The Thermal Properties of Isopentane

1894 Proc. Phys. Soc. London 13 602

(http://iopscience.iop.org/1478-7814/13/1/352)

LII. *The Thermal Properties of Isopentane.*

By SYDNEY YOUNG, *D.Sc., F.R.S., University College, Bristol.*

CONTENTS.

INTRODUCTION.

THE relations between the temperatures, pressures, and volumes of gases and liquids have been the subject of numerous experimental and mathematical investigations since the publication of the classical experimental researches of Andrews, and the great mathematical investigation of van der Waals on the continuity of the gaseous and liquid states of matter. Among the substances which have been most thoroughly studied are the elementary gases—oxygen, nitrogen, hydrogen; a few compounds which are gaseous under ordinary conditions, such as carbon dioxide and ethylene; and a few liquids, especially ether, the lower alcohols, and water.

The experiments on oxygen, hydrogen, and nitrogen have necessarily been chiefly carried out at temperatures far above their critical points, whilst with ethylene and carbon dioxide the range of temperature below the critical temperature at which observations have been made is small. It is also, as a rule, more difficult to fill a tube with a gas in a perfectly pure state than with a liquid.

Of the liquids examined, the alcohols and water behave abnormally in many respects, owing probably to the existence of complex molecules in the liquid state; and though the results obtained are of great interest, it is obvious that a thorough investigation of what may be termed normal substances should be carried out before the behaviour of such abnormal compounds can be properly understood.

None of the substances yet examined have given better results than ethyl ether. It can be obtained without great difficulty in a state of purity; it is possible to obtain results through a considerable range of temperature both above and below its critical temperature, and its critical pressure is moderately low.

Experiments on ether over a wide range of volume and temperature have been made by Ramsay and Young (Phil. Trans. 1887, A, p. 57), and also by Battelli (*Mem. della R. Ac. di Torino*, [2] xl. 1889), and up to extremely high pressures—though with a small range of volume—by Amagat (*Annales Chim. Phys.*, series 6, vol. xxix.), and by Barus (Phil. Mag. 1890, vol. xxx. p. 358).

The result of these investigations is to show that although the formula of van der Waals, $\left(p+\frac{a}{v^2}\right)(v-b)=\mathrm{RT}$, gives the general form of the isothermal curves very satisfactorily and, indeed, agrees well with the experimental results at large volumes, yet it cannot be regarded as sufficiently accurate at volumes near and below the critical volume.

At constant volume, however, since $\frac{a}{v^2}$ and $(v-b)$ are both constants, the formula of van der Waals may be reduced to the form $p=b\mathrm{T}-a$, where a and b are constants depending on the nature of the substance and on the volume*.

This relation was found to hold good by Amagat (*Comptes Rendus* (1882), xciv. p. 847) in the case of carbon dioxide and ethylene in the gaseous state and approximately in the liquid state, and by Ramsay and Young (Phil. Mag. May 1887, p. 435) in the case of ether in both the gaseous and liquid states.

Barus (*loc. cit.*) has shown that the law holds good for ether and some other substances in the liquid state up to a pressure of 1000 atm., but that there are deviations at higher pressures. Up to 1000 atm. he estimates the error as not greater than 2 or 3 degrees.

Further investigations by Ramsay and Young (Phil. Mag. August 1887, p. 195) have shown that the law is applicable, approximately at any rate, to methyl and ethyl and (Phil. Trans. 1889, A, p. 137) propyl alcohol, but that there are

* The symbols b and a in the equation $p=b\mathrm{T}-a$ have, of course, not the same meaning as in van der Waals's equation, but as they have been used in previous papers by Ramsay and myself I have thought it best to adhere to them.

considerable deviations in the case of water (Phil. Trans. 1892, A, p. 107).

Further experiments—up to very high pressures, though with a small range of volume—have been carried out by Amagat (*Ann. Chim. Phys.* loc. cit.), and his conclusions will be referred to later.

The number of substances that can be conveniently investigated through a sufficiently wide range of temperature both above and below the critical temperature and through a wide range of volume (in both the gaseous and liquid states) is very limited; it therefore seemed desirable to take advantage of the opportunity, afforded by the possession of a quantity of pure isopentane, to make as complete an investigation as possible of the relations between the temperature, pressure, and volume of this substance. It would be difficult to find a more suitable liquid; it is extremely stable and is readily freed from moisture by distillation over phosphorus pentoxide; its boiling-point is 27°·95; its critical temperature is 187°·8, and its critical pressure 25020 millim.

Experimental Results.

Preparation of Pure Isopentane.

A quantity of "pentane" was procured from C. A. F. Kahlbaum of Berlin, who has kindly informed me that the substance is obtained as a bye-product in the preparation of amylene from amyl alcohol, the admixed amylene being separated by means of bromine. The isopentane was shaken with concentrated sulphuric acid and afterwards repeatedly with a mixture of concentrated sulphuric and nitric acids. The action in each case was at first somewhat violent, but it moderated after several additions of the acids had been made.

After standing all night over sulphuric and nitric acids the isopentane was again repeatedly shaken with sulphuric acid—which was at first coloured a deep orange; it was then treated with a strong solution of potassium hydrate, washed with water, dried with solid potassium hydrate, and distilled*.

* It is possible that the substance might have been satisfactorily purified by treatment with bromine. The loss by evaporation would probably have been smaller and the process less troublesome.

The greater portion came over below 32°, but the temperature finally rose to 56°.

The isopentane, which in addition to the higher-boiling impurity contained a small quantity of a very volatile substance, was then fractionated ten times, and was finally collected in two fractions both of which boiled quite constantly at 27°·45 under a pressure of 748·5 millim.

Proofs of Purity of the Isopentane.

It seemed at first rather doubtful—from its method of formation and from its behaviour with sulphuric and nitric acids—whether the isopentane could be obtained in a pure state; but the impurities were removed without much difficulty by fractional distillation, and the following evidence leaves no doubt that the substance was satisfactorily purified:—

1. The two fractions boiled at precisely the same temperature and both quite constantly.
2. The specific gravities of the two fractions at 0° were practically identical (0·63925 and 0·63922).
3. The critical temperatures and pressures of the two fractions were in very close agreement (see p. 609).
4. The vapour-pressures of both fractions were determined at a great number of different temperatures and agreed very well together.
5. The vapour-pressure was found to be entirely independent of the relative volumes of liquid and vapour. The experimental results at two temperatures, 90° and 140°, have already been published in a paper read before the Physical Society (Phil. Mag. Dec. 1894, p. 569; *ante*, p. 271). The object of the paper was to show that the vapour-pressure *of a pure substance* at any temperature is independent of the relative volume of liquid and vapour; but since it is well known that the vapour-pressure of an impure liquid does depend on the volume*, the invariability of the vapour-pressure in the

* It is true that in a limited number of special cases a particular mixture of two substances at a given temperature exerts a lower vapour-pressure than any other mixture (*e. g.* formic acid and water), or a higher vapour-pressure (*e. g.* propyl alcohol and water), and that the vapour-pressure of such a mixture at that temperature is independent of the relative volumes of liquid and vapour; also that such a mixture

case of my specimen of isopentane may perhaps be adduced as evidence in favour both of the purity of this particular substance and of the behaviour of pure substances in general. In any case the other proofs of purity appear to be sufficient.

6. In the course of the determinations of the volume of a gram of vapour with a modified Hofmann's vapour-density apparatus the vapour-pressure was measured at a few temperatures, and a comparison of these pressures with those read from the curves constructed from the data obtained by the dynamical method shows that the agreement is satisfactory.

Vapour-Pressure.

Temperature.	Statical.	Dynamical.	Δp.	Δt.
10°·6	401·0	400·0	+1·0	−0·05
10·85	405·6	403·95	+1·65	−0·1
11·05	406·1	407·15	−1·05	+0·05
16·55	499·6	503·6	−4·0	+0·2

7. The agreement of the boiling-point, specific gravity, vapour-pressures at high temperatures, and critical constants with those of a specimen of isopentane prepared by G. L. Thomas and myself from amyl iodide.

Boiling-Point.

The isopentane was always distilled over phosphorus pentoxide immediately before being used for any determination, and there are thus a considerable number of observations of the boiling-point. They are given in the table below, together with the boiling-points corrected to 760 millim. pressure.

would boil at a constant temperature and distil unchanged in composition under that pressure; but it has been found in such cases that the composition of the mixture which has a maximum or minimum vapour-pressure (and a constant boiling-point) differs to some extent at different temperatures (and pressures). In such a case, therefore, it might be found at a certain temperature that the vapour-pressure of the mixture was independent of the relative volumes of liquid and vapour, but it is in the highest degree improbable that a similar result would be obtained with the same mixture at a widely different temperature.

The value of dp/dt at the boiling-point = 26·2 millim. The boiling-point, calculated from the constants for Biot's formula, is 27°·95.

Fraction A.			Fraction B.		
Pressure.	Temperature. Observed.	Temperature. Corrected to 760 mm.	Pressure.	Temperature. Observed.	Temperature. Corrected to 760 mm.
745·4	27°·3	27·85	748·5	27·45	27·9
748·5	27·45	27·9	751·1	27·55	27·9
749·0	27·55 *	27·95	751·2	27·6	27·95
751·2	27·6	27·95	751·5	27·65 *	27·95
753·5	27·7	27·95	752·4	27·65 *	27·95
758·9	27·9 *	27·95	759·1	27·95 *	28·0
759·1	27·95 *	28·0	761·7	28·0	27·95
761·9	28·0	27·95		Mean	27·95
765·3	28·15	27·95			
	Mean	27·95			

* The temperatures marked with an asterisk were determined with a Geissler's normal thermometer.

Boiling-Points by other Observers.

	Name.	Reference.	Pressure.	B.P.	B.P. reduced to 760 millim.
1.	Schmidt	*Annalen*, cclxvi. p. 282.	760·7	31°–33°	31°–33°
2.	Pawlewski	*Ber.* xvi. p. 2633.	760	..	31
3.	Schiff	*Annalen*, ccxx. p. 87.	760	..	30·5–31·5
4.	Perkin	Trans. Chem. Soc. xlv. p. 445.	760	..	29–32
5.	Thorpe and Rodger	Phil. Trans. clxxxv. A, p. 453.	760	..	30·4
6.	Schorlemmer	Proc. Roy. Soc. xvi.	760	..	30
7.	Goldstein	J. Russ. Chem. Soc. 1882, p. 45.	760	..	30·5
8.	Beilstein and Kurbatow ..	*Ber.* xiv. p. 1620.	..	..	30
9.	Wurtz	*Annalen*, cxxviii. p. 229.	..	..	28–30
10.	Pelouse and Cahours ..	*Jahresb.* xvi. p. 527.	..	..	30
11.	Lachowitz	*Annalen*, ccxx. p. 188.	..	..	29–30
12.	Frankland	Trans. Chem. Soc. iii. pp. 31 & 481.	734	30	31
13.	Just	*Annalen*, ccxx. p. 146.	..	..	30
14.	Landolt and Jahn .	*Zeit. Phys. Chem.* x. p. 290.	760	..	28
15.	Altschul	*Ibid.* xi. p. 590.	760	..	28

Mr. J. W. Rodger has kindly informed me that he has prepared specimens of isopentane from amyl iodide obtained from both Scotch and

Irish samples of amyl alcohol, and that they boiled within 0°·05 and 0°·02 respectively. The observed boiling-points were :—

From Irish amyl alcohol....	28°·04,
„ Scotch „ „	28°·01.

---

1. Obtained from Trommsdorff (from American petroleum) dried with phosphorus pentoxide and fractionated. Schmidt states that the sample contained a considerable quantity of normal pentane.
2. Source not stated.
3. Separated from commercial amylene by treatment with sulphuric acid diluted with its own weight of water. Residue treated with concentrated sulphuric acid until the acid was no longer coloured. Distilled and heated to 130° with sodium.

4–6. Specimens prepared by Schorlemmer from petroleum.

8. From Caucasian petroleum.
9. From crude amylene by action of bromine.
10. From American petroleum.
11. From petroleum from Galicia.
12. By action of zinc and water on amyl iodide.
13. By action of zinc and hydrochloric acid on amyl iodide.

14, 15. Separated from amylene by means of bromine. The substance is called "pentane."

As these observations of the boiling-point of isopentane, with the exception of those of Landolt and Jahn, Altschul, and Rodger, are considerably higher than mine, a specimen of isopentane was prepared by Thomas and myself from amyl iodide; the method of preparation and the observations of the boiling-point, specific gravity, and critical temperature and pressure are given in a separate paper. These observations agreed perfectly with those described in this paper. The boiling-point was 27°·95 at 760 millim.

Specific Gravity.

The specific gravity of each fraction was determined at two different temperatures by Sprengel's method as modified by Perkin. The weighings were reduced to a vacuum.

Temperature.	Fraction A.	Fraction B.
0°	0·63925	0·63922
14°·4	0·62514	
13°·45	...	0·62614

The specific gravity at 0° of the sample prepared by Thomas and myself was ·63935.

Specific Gravities by other Observers.

Name.	Sp. gr. at t°.		Sp. gr. at 0°.
Schiff	0·6282	at 13°·7	0·6416
Pelouse and Cahours	0·628	,, 18	0·6458
Frankland	0·6413	,, 11·2	0·6524
,,	0·6385	,, 14·2	0·6526
Just	0·6375	,, 13/13	0·6500
Bartoli and Stracciati*	0·6402	,, 0	0·6402
Landolt and Jahn	0·62656	,, 14·3	
,, ,,	0·62472	,, 16·2	Mean ... 0·64058†
,, ,,	0·62278	,, 18·2	
,, ,,	0·62074	,, 20·0	
Perkin	0·62479	,, 15/15	0·63893
,,	0·61590	,, 25/25	0·63888

The specific gravities at 0° were calculated from the observations at higher temperatures by means of the formula

$$D_t = 0{\cdot}63923 - 0{\cdot}0_3958\,t - 0{\cdot}0_513\,t^2.$$

This formula agrees very well with my experimental results up to 60°.

My observations agree very well with Perkin's, although the specimen examined by him boiled between 29° and 32°. It was prepared by Schorlemmer, and, no doubt, contained some normal pentane, the specific gravity of which differs but slightly from that of isopentane.

Critical Constants.

		Fraction A.		Fraction B.	
		Temperature. °	Pressure. millim.	Temperature. °	Pressure. millim.
With Aniline vapour as jacket ...	(1)	187·75	25020	187·75	25000
	(2)	187·8	25020		
,, Quinoline ,, ,, ...	(1)	187·85	25030	187·85	25020
	(2)	187·9	25020		

* *Beiblätter*, ix. p. 697.

† Landolt and Jahn calculate the specific gravity at 0° as 0·64116.

The mean values are :—

Critical temperature . . .	187°·8
Critical pressure	25015 millim.

The sample prepared by Thomas and myself gave the following results :—

Critical temperature . . .	187°·8.
Critical pressure	25030 millim.

The critical volume of a gram, calculated by the method of Cailletet and Mathias from the mean densities of liquid and saturated vapour at lower temperatures, is 4·266 cub. centim.

Critical Constants by other Observers.

	Temperature.	Pressure. millim.
Schmidt . . .	193°·0	
Pawlewski . .	194·8	
Altschul . . .	187·1	25300

It may be pointed out that Schmidt's sample of isopentane contained some normal pentane, which would raise the critical temperature, and that Pawlewski's observations of critical temperature are in most cases somewhat higher than mine. On the other hand, those of Altschul agree well in the few cases that can be compared. They are given in the table below :—

	Altschul.		Young.	
	Temperature.	Pressure.	Temperature.	Pressure.
	°	atm.	°	atm.
Normal Hexane ...	234·5	30·0	235·0	29·76
Benzene..............	290·5	50·1	288·5	47·9
Chlorobenzene	362·2	......	359·3 *	......

* Corrected for error in the boiling-point of mercury.

Vapour-Pressures at Low Temperatures.

The vapour-pressures at temperatures below the boiling-point under atmospheric pressure were determined by the dynamical method of Ramsay and Young (Trans. Chem. Soc. xlvii. p. 43).

For temperatures below 0° a thermometer by Warmbrunn, Quilitz, & Co. of Berlin was employed ; it had been standardized by the Physikalisch-Technische Reichsanstalt. The effect of alteration of pressure on the readings of the thermometer was ascertained and allowed for, and the very small correction for the heated column of mercury in the stem of the thermometer was also applied.

The logarithms of the vapour-pressures were mapped against the temperatures, and the values at each ten degrees were read from the curve. The observed pressures are given in the table below, and the pressures at even temperatures in the table on p. 613.

Vapour-Pressures at Low Temperatures.

Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.
			Sample A (1).				
°	millim.	°	millim.	°	millim.	°	millim.
−31·83	52·7	−26·18	71·85	−12·86	143·4	−3·48	221·6
−31·38	53·95	−23·59	83·2	−12·71	144·15	−0·81	249·7
−30·29	57·5	−23·01	84·9	− 9·45	168·4	+0·10	259·1
−28·88	62·3	−20·45	98·0	− 6·53	193·05		
−26·53	71·0	−16·13	122·1	− 6·45	193·5		
			Sample A (2).				
+2·55	290·5	11·65	422·5	20·9	587·6		
5·6	330·8	14·9	473·3	23·35	642·5		
9·0	377·3	17·95	529·4	25·95	705·2		
			Sample B (1).				
−31·08	54·75	−25·91	73·45	−14·24	134·05	−4·82	208·85
−29·47	60·1	−22·33	88·9	−10·38	161·35	−2·44	232·3
−29·04	61·75	−18·06	110·95	− 7·01	189·35	+0·07	259·4
			Sample B (2).				
+0·4	262·6	10·05	389·7	19·05	550·7	26·2	712·0
2·75	302·0	13·2	441·1	21·9	607·1	28·05	760·55
6·65	341·3	16·35	499·8	24·2	661·2		

Vapour-Pressures at High Temperatures.

The volumes of a gram of liquid and saturated vapour and the vapour-pressures at temperatures above the ordinary boiling-point were determined with the pressure apparatus employed in my previous researches. The tube containing the isopentane was heated by the vapour of pure liquids boiling under known pressures (Ramsay and Young, Trans. Chem. Soc. xlvii. p. 640; Young, ibid. lv. p. 483). The temperatures are those of an air-thermometer. The pressures, determined by means of air-gauges, are corrected for (1) the difference in height of the columns of mercury in the air-gauge and volume-tube; (2) the expansion of the heated column of mercury; (3) the pressure of the column of isopentane; (4) the deviation of air from Boyle's law, as determined by Amagat.

There were eight series of determinations, and, as a rule, four readings of pressure were taken at each temperature, the volume being altered as much as possible. The individual readings agreed very well together, and the mean values only are given in the following table (p. 613).

The constants for Biot's formula

$$\log p = a + b\alpha^t + c\beta^t$$

are given below.

$$a = 11{\cdot}371605;$$

$$b = -8{\cdot}030139, \quad \log b = 0{\cdot}9047231,$$

$$c = -1{\cdot}575796, \quad \log c = 0{\cdot}1975000;$$

$$\log \alpha = \bar{1}{\cdot}99968451,$$

$$\log \beta = \bar{1}{\cdot}99484097,$$

$$t = t^\circ \text{ C.} + 30.$$

The vapour-pressures calculated from Biot's formula are also given in the table.

Table of Vapour-Pressures.

Temperature.	Dynamical Method.	I. A.	II. B.	III. A.	IV. A.	V. B.	VI. A.	VII. A.	VIII. A.	Calculated.
−30	58·55	......	......	......	......	......	......	......	......	58·30
−20	100·0	......	......	......	......	......	......	......	......	100·06
−10	164·05	......	......	......	......	......	......	......	......	163·95
0	257·35	......	......	......	......	......	......	......	......	257·74
10	390·4	......	......	......	......	......	......	......	......	390·52
20	572·2	......	......	......	......	......	......	......	......	572·59
30	815·5	......	......	......	820	......	......	......	822	815·34
40	......	......	......	......	1137	......	......	......	1144	1131·1
50	......	......	1535	......	......	......	1536	1536	......	1533·2
60	......	......	2037	......	......	......	2036	......	......	2035·6
70	......	2657	2656	......	......	......	2657	......	......	2653·0
80	......	......	3385	3381	......	......	......	......	......	3400·8
90	......	4283	4281	4280	......	......	......	......	......	4295·6
100	......	......	5347	5344	......	......	......	......	......	5354·5
110	......	......	6583	6581	6586	6585	......	......	......	6596·1
120	......	......	8020	8020	8016	8016	......	......	......	8039·9
130	......	......	9685	9687	9682	9682	......	......	......	9706·7
140	......	11630	11640	11640	11630	11630	......	......	......	11620
150	......	13800	13800	13810	13800	......	......	......	......	13804
160	......	......	16320	16320	16320	......	......	......	......	16285
170	......	......	19110	19120	......	......	......	......	......	19094
176	......	......	......	20970	......	......	......	......	......	20950
180	......	......	22270	......	......	......	......	......	......	22262
183	......	......	......	23310	......	......	......	......	......	23288
185	......	......	24000	......	......	......	......	......	......	23992
186	......	......	......	24370	......	......	......	......	......	24350
187	......	......	24730	......	......	......	......	......	......	24713
187·4	......	......	......	24880	......	......	......	......	......	......
Critical 187·8	......	......	25010	25025	25020	......	......	......	......	25005

Volumes of a Gram of Liquid and Vapour.

In the first three series the mass of substance was determined by observing the volumes of liquid at a series of temperatures. These volumes were mapped against the temperatures and curves drawn through the points. The values at 0°, 13°·45, and 14°·4 were read off and were multiplied by the specific gravities at those temperatures.

For Series IV. and V. comparisons were made of the volumes of liquid and also of unsaturated vapour at a large number of different temperatures and pressures with those read from the curves constructed from the data obtained in the previous series.

The mass of substance in Series VI. was similarly ascertained by comparison of volumes with those read from the isothermals of Series IV. and V. at the same temperatures and pressures. So also with the remaining series, the calculated mass depended in each case on the data obtained in the preceding series.

A series of determinations of the volumes of unsaturated vapour was afterwards made by Thomas and myself in a modified Hofmann's apparatus, the mass of isopentane being determined by direct weighing. The smallest volumes of a gram in this series were nearly the same as the largest in Series VIII. with the pressure apparatus; and as the isothermals constructed from the observations with the modified Hofmann's apparatus were quite continuous with those of Series VIII., the determination of mass in this series—which might be charged with the cumulative errors of each preceding determination—was shown to be accurate.

Orthobaric Volumes of a Gram of Liquid.

The volumes at 0°, 13°·45, and 14°·4 were calculated from the specific gravities at the same temperatures. The observations were made under atmospheric pressure, but the correction of the volumes to the true vapour-pressures has not been made, as the difference would be inappreciable.

In the pressure apparatus the volumes of liquid up to 130° were read directly, the vapour being completely condensed and the pressure made as nearly as possible equal to the vapour-pressure. At and above 140° the liquid is very compressible, and the volumes were therefore calculated from a series of readings of the volumes of vapour and of the total volume of liquid and saturated vapour at each temperature by the method described in the Trans. Chem. Soc. lxiii. p. 1200.

The volumes of liquid (when all vapour is condensed) and of saturated vapour (when all liquid is evaporated) may also be ascertained very simply by the following graphical method :—

Let the total volume (liquid and uncondensed vapour) at any reading $=$ V.

" volume of saturated vapour at the same time $= v$.

" " of liquid when all condensed $=$ A.

" " of saturated vapour when all evaporated $=$ B.

" ratio of the specific volume of saturated vapour to that of liquid $=$ R.

" volume of liquid (*i.e.* $V - v$) $= A - n$.

Then the volume of vapour, $v = nR$,

and the total volume, $$V = A - n + nR,$$

or $$V = A + n(R-1).$$

Call $$\frac{R-1}{R} = c\,;$$

then $$V = A + \frac{R-1}{R} . nR$$
$$= A + cv.$$

If we map the total volumes, (V_1, V_2, &c.) against the volumes of saturated vapour (v_1, v_2, &c.) and draw a straight line through the points, then when

$$v = 0, \quad V = A,$$

and when $$v = V, \quad V = B.$$

Again, let the volumes of saturated vapour v at any reading $= B - m$.

Also call the volume of liquid v' when the total volume $=$ V, so that $v' = \frac{m}{R}$.

Then the total volume, $V = B - m + \frac{m}{R}$
$$= B - m . \frac{R-1}{R} .$$

Make $$R-1=c',$$
then
$$V=B-(R-1)\cdot\frac{m}{R}$$
$$=B-c'v'.$$

If we map the total volumes V_1, V_2, &c., against the volumes of liquid v_1', v_2', &c., then when

$$v'=0,\quad V=B,$$
and when
$$v'=V,\quad V=A.$$

The first method is better suited for the volumes of saturated vapour, the second for the volumes of liquid.

The orthobaric volumes of a gram of liquid, calculated from the experimental data, and also those read from the curves constructed from the observed values are given in the following table :—

Orthobaric Volumes of a Gram of Liquid.

Temp.	From Specific Gravities.	Series I.	Series II.	Series III.	Mean.	From Curves.
°	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
0	1·5644	......	......	......	1·5644	1·5644
10	......	1·5885	......	......	1·5885	1·5885
13·45	1·5971	......	......	......	1·5971	1·5972*
14·4	1·5996	......	......	......	1·5996	1·5996*
20	......	1·6140	......	......	1·6140	1·6141
30	......	1·6415	1·642	......	1·6415	1·6413
40	......	1·6700	1·670	......	1·6700	1·6700
50	......	1·7005	1·700	......	1·7005	1·7005
60	......	1·7330	1·734	......	1·7335	1·7329
70	......	1·7680	1·768	......	1·7680	1·7679
80	......	1·8045	1·806	......	1·8050	1·8055
90	......	1·8475	1·847	......	1·8475	1·8475
100	......	1·8945	1·894	......	1·8945	1·8940
110	......	1·9455	1·945	......	1·9455	1·9455
120	......	2·0040	2·003	......	2·0035	2·0037
130	......	2·0720	2·072	......	2·0720	2·0720
140	......	2·1525	2·156	2·153	2·1540	2·1530
150	......	2·2490	2·252	2·248	2·2495	2·2500
160	......	......	2·378	2·377	2·3775	2·3780
170	......	......	2·555	2·555	2·5550	2·5550
176	......	......	......	2·707	2·7070	2·7070
180	......	......	2·859	......	2·8590	2·8580
183	......	......	......	3·020	3·0200	3·0200
185	......	......	3·183	......	3·1830	3·1830
186	......	......	......	3·303	3·3030	3·3020
187	......	......	3·500	......	3·5000	3·5000
187·4	......	......	......	3·622	3·6220	3·6220
Critical 187·8	......	......	......	......	......	4·2660†

* From densities calculated from the formula

$$D_t=0·63923-0·0_3958\,t-0·0_513\,t^2.$$

† By the method of Cailletet and Mathias.

Orthobaric Volumes of a Gram of Vapour.

The volumes of saturated vapour were determined by three different methods :—

I. With the pressure apparatus from a series of four readings of the total volume of liquid and uncondensed vapour and of the vapour at each temperature at and above 110°.

This method (Trans. Chem. Soc. lxiii. p. 1200) gives very good results at high temperatures, but is not accurate when the ratio of the volume of a gram of saturated vapour to that of liquid is large. It has been described and recommended by Amagat (*Compt. Rend.* cxiv. p. 1093).

The graphical method described on p. 614 may be employed to ascertain the volume of saturated vapour when all the liquid is evaporated, and this, divided by the mass of substance in the tube, gives the volume of a gram of saturated vapour.

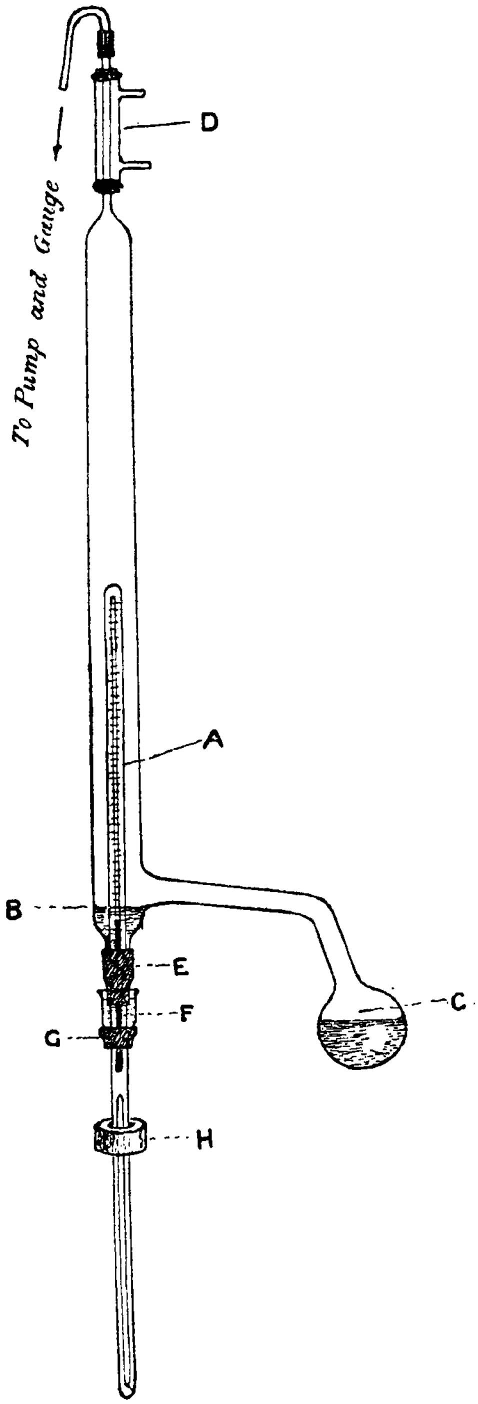
II. By heating a known quantity of liquid in a graduated sealed tube (Young, Trans. Chem. Soc. lix. p. 37 ; lxiii. p. 1201).

The method was originally devised for the purpose of determining the specific volumes (both as liquid and as saturated vapour) of liquids that attack mercury, but it has been found very convenient—in a modified and simpler form—for the determination of the volumes of a gram of the saturated vapours of ordinary substances whose specific volumes, as liquid, are known. The form of the sealed tube, the method of filling it, and the arrangements for heating it, are the same as are described in the paper referred to (vol. lix. pp. 40 and 41), but it is, of course, unnecessary to keep the lower part of the tube cool, and the water-jacket below is therefore not required.

The tube A is at first placed in the position shown in the diagram (fig. 1), with the level of the liquid in the tube below the condensed liquid B in the jacket. The liquid in the bulb C is then boiled—with the pressure rather lower than that corresponding to the lowest temperature required—and when the vapour has reached the condenser* D the sealed tube is slowly pushed up through the indiarubber tube E until the whole of the liquid in it is well above the surface of the condensed liquid B. The indiarubber tube should be kept under water for a day or two before being used, and should be surrounded by water until the sealed tube has been pushed up into its

* For liquids boiling above 160° a condenser is not required.

Fig. 1.



final position, otherwise considerable difficulty may be experienced in moving the sealed tube through it. The little glass tube F, filled with water and provided with a very short indiarubber tube G moving easily over the sealed tube, serves to keep the indiarubber tube E moist. The sealed tube is easily centred by means of a perforated cork H, held in position by a clamp and retort-stand. After the tube is in position the pressure under which the liquid in C is boiling is slowly raised until it corresponds to the required temperature, and a reading of the height of the liquid is then taken. A second reading is then taken after two or three minutes, and if the volume of liquid is smaller readings are taken from time to time until constancy is attained.

At moderate temperatures the volume of liquid should become constant almost immediately, but near the critical point the evaporation of the liquid becomes much slower, and this is especially the case if any appreciable amount of air or permanent gas is left in the tube. The amount of permanent gas must be exceedingly small, otherwise the results obtained are found to be inaccurate, owing probably to partial condensation of the vapour on the sides of the tube.

After the reading has become constant the pressure is again slowly raised—care being taken not to drive down the vapour below the top of the sealed tube—until the next temperature is reached.

If the top of the tube is cooled, condensation takes place in it, and there is danger of liquid remaining in contact with the walls of the tube, and of the apparent volume of liquid being therefore too small.

For the same reason it is advisable to begin treating the tube in the manner described, for if the tube were placed in its final position at the beginning of the experiment the liquid would boil and would collect at the top of the tube.

III. From the isothermals; the points of intersection of the curves representing the unsaturated vapour with the horizontal lines of vapour-pressure give the volumes of saturated vapour.

The logarithms of the volumes were mapped against the temperature, and the smoothed values read from the curve. These are given in the following table together with the values obtained by the three methods described above.

Orthobaric Volumes of a Gram of Vapour.

Temperature.	In Pressure Apparatus.				Sealed Tube Method.		From Isothermal Curves.	Mean.	From Curve.
	II.	III.	IV.	V.	I.	II.			
°	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
10·8	......	......	......	......	......	......	591·5*	591·5	
10	......	......	......	......	......	......	......	......	607·5
20	......	......	......	......	......	......	......	......	424·0
30	......	......	......	......	301	......	304·5	303	303·0
40	......	......	......	......	224	......	223·0	223·5	223·2
50	......	......	......	......	168·5	......	168·0	168·2	167·6
60	......	......	......	......	128·0	......	128·0	128·0	127·9
70	......	......	......	......	98·4	......	99·00	98·7	98·9
80	......	......	......	......	77·7	......	77·95	77·8	77·9
90	......	......	......	......	61·8	......	61·87	61·85	61·85
100	......	......	......	......	49·65	......	49·35	49·5	49·45
110	......	......	38·9	39·6	39·85	40·2	39·83	39·7	39·80
120	......	......	32·3	32·3	......	32·6	32·20	32·35	32·20
130	......	......	26·05	26·05	......	26·3	26·10	26·10	26·10
140	21·00	21·20	21·10	21·05	......	21·15	21·15	21·10	21·15
150	17·13	17·18	17·13	......	......	17·19	17·14	17·15	17·14
160	13·69	13·71	13·73	......	......	13·69	13·72	13·71	13·72
170	10·73	10·73	......	......	......	10·72	10·73	10·73	10·71
176	......	9·075	......	......	......	......	9·07	9·07	9·08
180	7·952	......	......	......	......	7·955	7·95	7·952	7·95
183	......	7·045	......	......	......	......	7·035	7·040	7·05
185	6·348	......	......	......	......	6·375	6·35	6·354	6·355
186	......	5·963	......	......	......	5·963	......	5·963	5·965
187	5·453	......	......	......	......	......	......	5·453	5·455
187·4	......	5·126	......	......	......	......	......	5·126	5·125
187·8 †	......	......	......	......	......	......	......	4·266	4·266

* From determinations in the modified Hofmann's apparatus (Young and Thomas).
† By the method of Cailletet and Mathias.

Volumes of a Gram of Liquid and of Unsaturated Vapour.

Eight series of determinations were made in the pressure apparatus.

Series.	Specimen of Isopentane employed.	Mass of Isopentane.	Data obtained.
		gram.	
I.	A	0·30244	Volumes of liquid up to 150°.
II.	A	0·09504	Volumes of liquid to critical point; a few volumes of unsaturated vapour at and above 176°; volumes above the critical point to 280°.
III.	B	0·11516	
IV.	A	0·03405	Volumes of unsaturated vapour from 140° to critical point; volumes above critical point to 280°.
V.	B	0·03010	
VI.	B	0·00888	Volumes of vapour at and above 90°.
VII.	B	0·003743	,, ,, ,, 50°.
VIII.	B	0·001225	,, ,, ,, 30°.

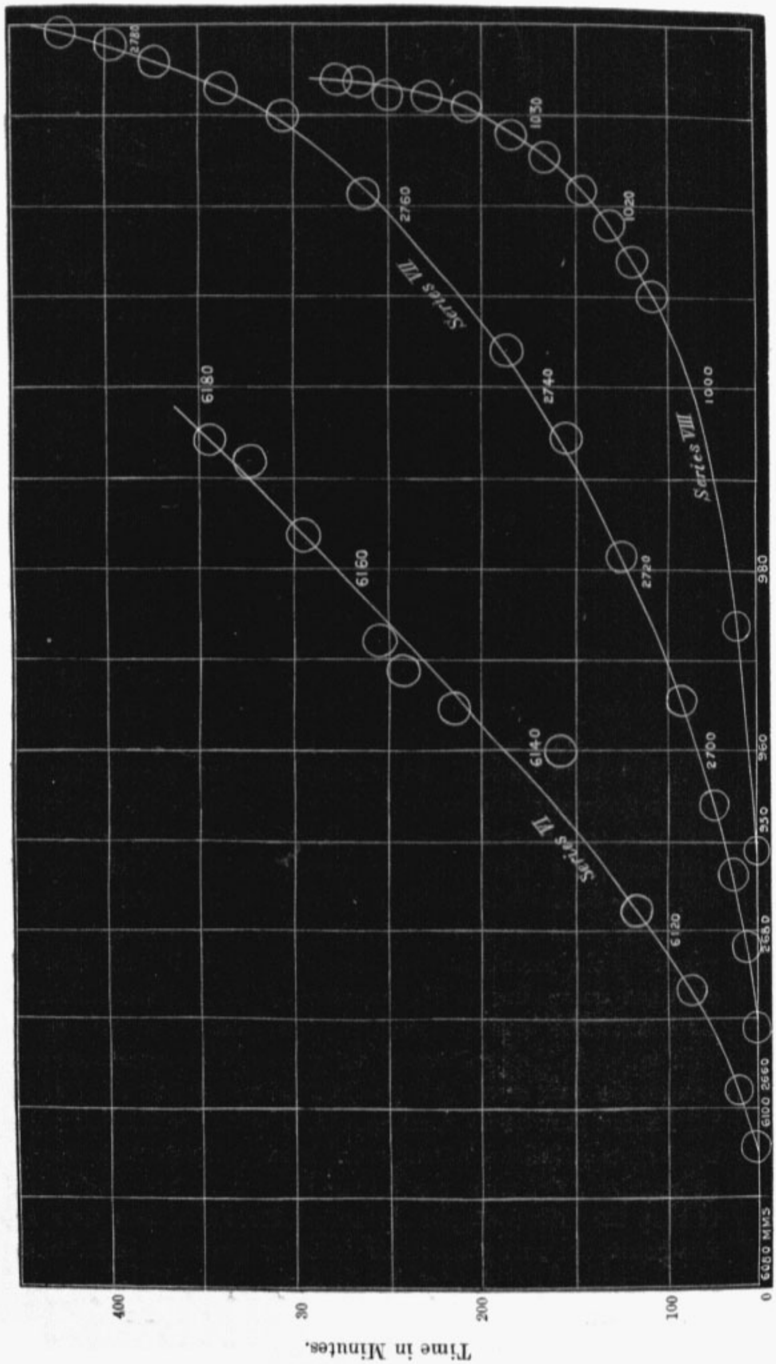
In Series VI. to VIII. the volumes were determined at temperatures up to 280°.

Correction of Pressures.—In addition to the corrections for the difference in height of the columns of mercury, the expansion of the heated column, and the deviation of air from Boyle's law, there is another which is of importance at the highest temperatures, but is somewhat difficult to estimate. This is the correction for the vapour-pressure of mercury.

It has been proved experimentally that the vapour of mercury penetrates a column of liquid over it with extreme slowness, and no correction has therefore been applied in the measurement of the vapour-pressure of isopentane or even of other substances with much higher critical temperatures.

When, however, there is only gas over the mercury the vapour of the metal diffuses slowly through it, the rate of diffusion increasing as the pressure of the gas is diminished. Even with the smallest quantity of isopentane at its largest volume, when the pressure of the gas was little over an atmosphere, the maximum pressure at 280° was not attained until after about four hours' heating. It is quite certain that with the larger quantities of substance a much longer time would be required, and as it was impossible, owing to other work, to keep the tube continuously heated for more than four or five hours, the only plan was to make an approximate estimate of the pressure exerted by the mercury-vapour.

Fig. 2.



2780
1030
2760
1020
Series VII
6180
2740
1000
Series VIII
6160
2720
980
6140
2700
960
Series VI
950
6120
2680
6100
2660
6080 MMS
400
300
200
100
0
Time in Minutes.

In the determinations of the volumes of a gram of unsaturated vapour the readings were always taken with diminishing volume, and at the higher temperatures the tube was heated for several hours with the substance at its largest volume. Readings were taken at short intervals, and were plotted against the time so as to get an idea of the rate of increase of the pressure.

The time-curves at 280° for the last three series are given in fig. 2. It will be seen that in Series VIII. the rise of pressure was at first very rapid, but that after two hours it had become very slow, and that the pressure after four hours was practically constant. The vapour-pressure of mercury at 280° is 158 millim., and the measured rise of pressure was 85 millim. The difference is, no doubt, due to the fact that the readings could not be begun until after the tube had been heated for some little time.

In Series VII. the rise was at first not quite so rapid as in Series VIII., and it was not until the tube had been heated for six hours that approximate constancy was attained. In this case the measured rise of pressure was 110 millim.

In Series VI. the rate of increase of pressure was much slower than in the later series, and the pressure was far from constant after five hours; the last reading was 78 millim. higher than the first.

It appears then that with the two smallest quantities of isopentane the mercury-vapour, after a sufficient time, exerted its full pressure, but that with the larger quantities the maximum pressure was not attained; also that when there is a column of liquid over the mercury no appreciable pressure is exerted by the vapour of the metal.

It was assumed that in Series II. and III. the vapour-pressure of the mercury amounted to one fourth of its maximum value; in Series IV. and V. to one half, in Series VI. to three quarters, and that in the last two series the full vapour-pressure was exerted*.

The time-curves for Series VII. and VIII. show that the error caused by assuming that the mercury-vapour exerted its full pressure cannot amount to more than one or two

* In Series VII. the tube was heated for six hours at 250° and 280°, and for over four hours at 200° and 220°.

millim. in Series VIII., and to three or four millim. in Series VII.; and it is very unlikely that in the other series the error can amount to so much as a fourth of the maximum vapour-pressure of mercury. In Series VI., for instance, it is certain that the actual pressure exerted by the mercury-vapour was greater than half and less than the whole maximum pressure. At 280° the vapour-pressure of mercury is 158 millim., the rise of pressure actually measured 78 millim., and the pressure assumed to be exerted by the mercury vapour 118 millim. The error is therefore considerably less than 40 millim. At the largest volume the uncorrected pressure was 6174 millim., and the extreme error would therefore be under 0·7 per cent.

This is by far the worst case, for the vapour-pressure of mercury diminishes rapidly with fall of temperature, whilst with the larger quantities of isopentane the total pressure is proportionately increased. Thus, at 260° (Series VI.) the extreme error, calculated in the same way, would be 0·4 per cent., at 240° 0·25 per cent., at 200° 0·08 per cent., whilst at 280° (Series V.) it would be just over 0·2 per cent., and at 280° (Series III.) less than 0·1 per cent.

At temperatures above 150° the jacketing tube was protected from draughts and from loss of heat by radiation by an outer cylindrical glass tube about 8 or 10 millim. wider than the jacketing tube, the space at the top between the two tubes being closed by asbestos to prevent the upward current of air which would otherwise be formed. It was still possible that the tube containing the isopentane lost some heat by radiation and that its temperature was therefore a little too low.

In order to find whether this was the case the outer glass tube was covered with sheet asbestos after the eleventh reading at 280° in Series VIII. had been taken. It will be seen that the last two readings, with the tube doubly protected, fall accurately on the time-curve constructed from the previous readings.

Similar experiments had been made with the l rger quantities of isopentane, but in no case was any alteration produced by covering the outer tube with asbestos. It may therefore be concluded that up to 280° the cylindrical glass tube affords sufficient protection from radiation.

The experimental results are given in the following Tables :—

Volumes of a Gram of Liquid and of Unsaturated Vapour.

Series I.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure millim.	Volume. cub. cm.
10°......	790	1·5890	50°......	43960	1·6710	100° ...	33240	1·8500
	4030	1·5870	(*cont.*)	50660	1·6675	(*cont.*)	38960	1·8420
	7960	1·5850		54840	1·6655		44050	1·8355
	11520	1·5840	60°......	2040	1·7330		50760	1·8270
	15140	1·5825		5300	1·7305		54950	1·8225
	20070	1·5810		8090	1·7275	110° ...	6580	1·9455
	26310	1·5780		11690	1·7245		8460	1·9405
	32720	1·5755		15370	1·7215		11740	1·9335
	38350	1·5735		20360	1·7180		15420	1·9260
	43360	1·5715		26680	1·7125		20420	1·9170
	49970	1·5685		33180	1·7080		26750	1·9050
	54100	1·5675		38870	1·7035		33260	1·8945
15°·6 ...	810	1·6025		43960	1·7000		38990	1·8845
	4100	1·6015		50650	1·6955		44100	1·8765
	8110	1·5995		54840	1·6920		50800	1·8670
	11720	1·5975	70°......	2690	1·7680		54990	1·8610
	15420	1·5960		5300	1·7660	120° ...	8020	2·0040
	20530	1·5945		8100	1·7620		10310	1·9970
	26760	1·5915		11700	1·7590		15400	1·9835
	33300	1·5885		15380	1·7550		20390	1·9705
	39040	1·5855		20380	1·7515		26700	1·9560
	44150	1·5835		26710	1·7450		33200	1·9420
	50880	1·5820		33210	1·7395		38900	1·9305
	55080	1·5795		38920	1·7345		43990	1·9215
30°......	820	1·6415		44020	1·7310		50700	1·9105
	4110	1·6385		50720	1·7260		54880	1·9035
	8110	1·6365		54910	1·7220	130° ...	9670	2·0720
	11730	1·6345	80°......	3390	1·8045		11740	2·0640
	15410	1·6325		5620	1·8020		15420	2·0505
	20430	1·6300		8090	1·7990		20430	2·0330
	26770	1·6265		11690	1·7955		26750	2·0150
	33300	1·6235		15360	1·7910		33260	1·9975
	39020	1·6205		20360	1·7855		38970	1·9835
	44130	1·6185		26880	1·7795		44070	1·9710
	50860	1·6155		33200	1·7730		50770	1·9570
	55050	1·6135		38910	1·7675		54970	1·9485
40°......	1110	1·6700		44000	1·7625	140° ...	11640	2·1525
	4110	1·6680		50700	1·7565		13030	2·1450
	8100	1·6660		54890	1·7525		15360	2·1320
	11710	1·6630	90°......	4290	1·8475		20330	2·1100
	15390	1·6610		6000	1·8450		26610	2·0835
	20400	1·6580		8110	1·8420		33070	2·0615
	26740	1·6535		11710	1·8365		38740	2·0440
	33250	1·6505		15400	1·8315		43800	2·0290
	38980	1·6470		20400	1·8255		50460	2·0120
	44070	1·6445		26720	1·8170		54620	2·0015
	50790	1·6415		33230	1·8090	150° ...	13800	2·2490
	54990	1·6385		38950	1·8025		15370	2·2365
50°......	1530	1·7005		44040	1·7975		17740	2·2190
	5290	1·6975		50750	1·7910		20340	2·2010
	8080	1·6950		54940	1·7860		26620	2·1645
	11680	1·6925	100° ...	5360	1·8945		33100	2·1335
	15360	1·6900		8130	1·8900		38780	2·1110
	20350	1·6870		11730	1·8830		43840	2·0920
	26670	1·6830		15410	1·8765		50520	2·0700
	33170	1·6785		20410	1·8690		54680	2·0580
	38870	1·6740		26740	1·8590			

Series II.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
30° ...	800	1·642	130° ...	36770	1·989	187°·8	29110	2·791
	7920	1·637	(*cont.*)	47250	1·966	(Critical)	31330	2·700
	15180	1·632	140° ...	11640	2·156	(*cont.*)	34600	2·608
	31400	1·624		15230	2·133		39480	2·517
	46780	1·617		25540	2·090		46740	2·426
40° ...	1100	1·670		36620	2·050	190° ...	25550	5·739
	7900	1·667		46920	2·021		25660	5·371
	15140	1·661	150° ...	13800	2·252		25760	4·999
	31350	1·652		17630	2·219		25860	4·628
	46710	1·643		25560	2·168		25880	4·258
50° ...	1535	1·700		36650	2·118		25930	3·892
	7930	1·695		46950	2·081		26170	3·523
	15200	1·690	160° ...	16320	2·378		26410	3·340
	31450	1·678		17380	2·360		26980	3·156
	46860	1·669		19950	2·329		28230	2·974
60° ...	2037	1·734		25200	2·279		29300	2·882
	7930	1·729		31100	2·237		30930	2·792
	15200	1·723		36130	2·205		33300	2·700
	31450	1·710		40560	2·182		36820	2·608
	46870	1·698		46270	2·156		41900	2·518
70° ...	2656	1·768	170° ...	19110	2·555		49310	2·426
	7930	1·762		20580	2·512	195° ...	27010	5·740
	15190	1·754		25200	2·425		27220	5·372
	31430	1·742		31100	2·354		27430	5·000
	46830	1·728		36130	2·307		27630	4·629
80° ...	3385	1·806		40540	2·275		27840	4·259
	8010	1·799		46270	2·238		28100	3·892
	15340	1·791	180° ...	22270	2·859		28610	3·523
	31720	1·774		23440	2·756		29130	3·340
	47250	1·759		27260	2·602		30090	3·157
90° ...	4280	1·847		31100	2·517		31790	2·974
	8000	1·842		36130	2·439		33150	2·883
	15310	1·832		40550	2·388		35110	2·792
	31680	1·811		46260	2·338		37900	2·700
	47220	1·793	185° ...	24000	3·183		41810	2·609
100° ...	5350	1·894		24260	3·082		47470	2·518
	7990	1·888		25170	2·928	200° ...	28410	5·741
	15300	1·875		27220	2·773		28720	5·372
	31660	1·853		29640	2·673		29070	5·001
	47170	1·833		32530	2·594		29420	4·630
110° ...	6583	1·945		36060	2·522		29790	4·260
	8000	1·943		40470	2·458		30340	3·893
	15300	1·927		46170	2·395		31180	3·524
	31660	1·897	187°·8	24800	5·739		31970	3·340
	47180	1·872	(Critical)	24960	5·371		33240	3·157
120° ...	8020	2·003		24990	4·999		35450	2·975
	10190	1·999		25000	4·628		37070	2·883
	20340	1·970		25010	4·258		39380	2·792
	31690	1·946		25020	3·892		42490	2·701
	47200	1·916		25070	3·523		46880	2·609
130° ...	9685	2·072		25190	3·339	210° ...	31170	5·742
	15340	2·048		25650	3·156		31740	5·374
	25710	2·019		26670	2·974		32350	5·002

Series II. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
210° ...	33020	4·631	220° ...	44830	3·250	240° ...	47280	4·080
(*cont.*)	33790	4·261	(*cont.*)	46250	3·159	(*cont.*)	48020	3·989
	34830	3·894		48060	3·067		48800	3·897
	35500	3·710	230° ...	35620	5·745	250° ...	42020	5·748
	36420	3·525		37700	5·377		43600	5·379
	37730	3·341		38860	5·004		45420	5·007
	39640	3·158		40160	4·633		46480	4·821
	41000	3·066		41780	4·263		47510	4·635
	42710	2·975		42800	4·079		48150	4·543
	44980	2·884		43970	3·896		48760	4·450
	48020	2·793		45460	3·712	260° ...	44670	5·749
220° ...	33910	5·744		46230	3·619		45570	5·565
	34700	5·375		47290	3·526		46490	5·381
	35570	5·003		48420	3·435		47550	5·194
	36540	4·632	240° ...	39350	5·747		48030	5·102
	37790	4·262		40620	5·378		48660	5·008
	38540	4·078		42140	5·006	270° ...	47380	5·751
	39410	3·895		43840	4·634		47880	5·659
	40440	3·711		44870	4·449		48400	5·566
	41750	3·525		45980	4·264		48830	5·475
	43620	3·342						

Series III.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume cub. cm.
160° ...	16320	2·377	176° ...	27130	2·508	186° ...	23900	7·177
	16420	2·375	(*cont.*)	29550	2·467		24030	6·954
	18220	2·350		32450	2·426		24130	6·731
	20440	2·325		35970	2·383		24230	6·507
	23290	2·296		40370	2·340		24290	6·282
	27110	2·264		46070	2·298		24360	6·057
	32420	2·227		49610	2·273		24370	5·963
	38010	2·193		53710	2·249		,,	3·303
	43000	2·170	183° ...	23160	7·397		25110	3·030
	49570	2·140		23210	7·286		26080	2·902
	53680	2·126		23260	7·176		27150	2·822
170° ...	19120	2·555		23300	7·064		28300	2·757
	19290	2·545		23310	7·045		29560	2·704
	20470	2·513		,,	3·020	187°·4	24350	6·954
	23320	2·455		23320	3·008		24570	6·508
	27120	2·399		24160	2·883		24740	6·057
	32430	2·339		25080	2·805		24800	5·832
	38020	2·292		27120	2·698		24840	5·608
	43010	2·258		29530	2·619		24870	5·384
	49580	2·218		32430	2·550		24880	5·126
	53680	2·199		35950	2·490		,,	3·622
176° ...	20970	2·707		40350	2·429		24890	3·603
	21810	2·660		46040	2·372		24910	3·492
	23320	2·602		49570	2·343		24990	3·382
	25090	2·551		53680	2·314		25120	3·281

Series III. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
187°·4	25256	3·205	190° …	25180	6·508	205° ..	29960	5·610
(*cont.*)	26079	3·016	(*cont.*)	25400	6·058	(*cont.*)	30530	5·162
	26241	2·992		25590	5·608		31090	4·718
	27153	2·900		25710	5·160		31780	4·271
	27313	2·883		25780	4·716		32740	3·826
	28302	2·818		25850	4·269		33490	3·605
	28472	2·807		25950	3·824		34560	3·384
187°·75	24430	6·954		26040	3·603		36370	3·162
(Critical)	24550	6·731		26300	3·382		37760	3·052
	24640	6·508		26940	3·160		39660	2·941
	24750	6·282		28560	2·939		42360	2·831
	24820	6·057		30170	2·829		46260	2·720
	24880	5·832		32780	2·718		52090	2·610
	24940	5·608		36810	2·608	210° …	29350	6·958
	24970	5·384		43080	2·497		30000	6·511
	25000	5·160		53320	2·387		30660	6·061
	25010	4·938	195° …	26050	6·955		31340	5·611
	25020	4·716		26410	6·509		32030	5·163
	25030	4·268		26740	6·059		32840	4·718
	25030	3·824		27050	5·609		33730	4·271
187°·8	25040	3·603		27320	5·161		35040	3·826
(Critical)	25110	3·382		27560	4·717		36010	3·605
	25610	3·160		27810	4·270		37410	3·384
	26140	3·050		28150	3·825		39580	3·162
	26970	2·939		28450	3·604		41210	3·052
	28430	2·829		28980	3·383		43500	2·941
	30790	2·718		30000	3·161		46580	2·831
	34570	2·608		30880	3·051		51040	2·720
	40670	2·497		32220	2·940		53910	2·660
	46050	2·431		34200	2·830	220° …	31480	6·959
	49580	2·394		37150	2·719		32330	6·513
	53680	2·361		41770	2·609		33260	6·062
188°·0	24910	6·057		48930	2·498		34170	5·612
	25010	5·608		53150	2·449		35180	5·164
	25070	5·160	200° …	27180	6·956		36330	4·719
	25090	4·716		27630	6·510		37730	4·272
	25100	4·492		28080	6·059		39720	3·827
	25100	4·268		28520	5·609		41080	3·606
	25110	4·046		28890	5·161		43100	3·385
	25130	3·824		29310	4·717		44460	3·274
	25160	3·603		29750	4·270		46150	3·163
	25300	3·382		30410	3·825		48450	3·053
188°·3	24940	6·057		30930	3·604		51170	2·942
	25070	5·608		31740	3·383		53960	2·857
	25140	5·160		33150	3·161	230° …	33610	6·961
	25170	4·938		34310	3·051		34650	6·515
	25180	4·716		35910	2·940		35750	6·064
	25190	4·492		38220	2·830		36940	5·614
	25190	4·268		41710	2·719		38260	5·165
	25210	4·046		46900	2·609		39800	4·720
	25220	3·824		53160	2·516		41750	4·273
	25250	3·603	205° ..	28200	6·957		44440	3·828
	25400	3·382		28820	6·510		46360	3·607
190° …	24920	6·954		29390	6·060		47640	3·496

Series III. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
230° ...	49010	3·386	250° ...	42550	5·616	270° ...	41870	6·968
(*cont.*)	50780	3·275	(*cont.*)	44510	5·168		43670	6·522
	52880	3·164		46890	4·723		45690	6·069
240° ...	35700	6·963		48350	4·500		48030	5·619
	36950	6·516		49910	4·275		49320	5·395
	38310	6·065		51900	4·053		50700	5·170
	39750	5·615		53000	3·940		52230	4·948
	41440	5·167	260° ...	39850	6·967		53070	4·837
	43360	4·721		41440	6·520	280° ...	43890	6·970
	45930	4·274		43240	6·068		459[illegible]0	6·523
	47490	4·052		45280	5·618		48240	6·071
	49370	3·829		47590	5·169		49410	5·846
	51780	3·608		48920	4·947		50770	5·621
	53320	3·497		50430	4·724		52170	5·396
250° ...	37820	6·965		52170	4·501		52980	5·284
	39210	6·518		53080	4·388		53760	5·172
	40760	6·066						

Series IV.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
150° ...	12870	19·39	176° ...	18230	13·15	183° ...	23030	7·585
	13120	18·77	(*cont.*)	19090	11·91	(*cont.*)	23180	7·280
	13370	18·15		19950	10·67		23260	7·095
	13600	17·52		20360	10·05	185° ...	15020	19·41
160° ...	13520	19·40		20750	9·435		15720	18·16
	14080	18·15		20920	9·130		16480	16·91
	14670	16·89	180° ...	14730	19·41		17300	15·65
	14980	16·27		15400	18·16		18190	14·40
	15290	15·64		16130	16·90		19130	13·16
	15610	15·02		16910	15·65		20110	11·91
	15940	14·39		17750	14·40		21130	10·67
	16260	13·77		18620	13·15		22150	9·440
170° ...	14130	19·40		19540	11·91		23070	8·205
	14740	18·15		20470	10·67		23460	7·585
	15380	16·89		21360	9·440		23780	6·970
	16110	15·64		21770	8·820		23910	6·665
	16850	14·39		22130	8·200		24000	6·355
	17240	13·77		22260	7·955	186° ...	21260	10·67
	17620	13·16	183° ...	14900	19·41		22290	9·440
	18020	12·53		15590	18·16		23270	8·205
	18400	11·91		16330	16·90		23670	7·585
	18770	11·29		17140	15·65		24010	6·970
	18940	10·98		18000	14·40		24150	6·665
176° ...	14480	19·41		189[illegible]0	13·16		24270	6·355
	15130	18·15		19880	11·91		24350	6·045
	15840	16·90		20870	10·67	187°·85	15190	19·41
	16600	15·64		21820	9·440	(Critical)	15900	18·17
	17380	14·39		22680	8·205		16680	16·91

Series IV. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
187°·85	17510	15·65	210° ...	17310	18·17	250° ...	18760	19·44
(Critical)	18430	14·40	(*cont.*)	18220	16·92		19780	18·19
(*cont.*)	19390	13·16		19220	15·66		20920	16·94
	20400	11·91		20300	14·41		22170	15·68
	21480	10·67		21500	13·17		23600	14·43
	22560	9·440		22820	11·92		25190	13·18
	23570	8·205		24280	10·68		27010	11·93
	24430	6·970		25840	9·445		29130	10·69
	24910	5·740		27520	8·210		31520	9·455
	25000	5·125		29300	6·975		34340	8·220
	25020	4·505		31150	5·740		37740	6·980
	25030	3·890		33260	4·505		42030	5·750
190° ...	15310	19·41	220° ...	17060	19·43		44630	5·130
	16040	18·17		17930	18·18	260° ...	19320	19·45
	16840	16·91		18900	16·93		20360	18·20
	17690	15·65		19960	15·66		21570	16·94
	18600	14·40		21150	14·41		22910	15·68
	19590	13·16		22430	13·17		24410	14·43
	20640	11·91		23870	11·92		26100	13·18
	21750	10·67		25500	10·68		28050	11·94
	22880	9·440		27270	9·450		30300	10·70
	23940	8·205		29250	8·210		32920	9·460
	24900	6·970		31440	6·975		36050	8·220
	25540	5·740		33860	5·745		39780	6·980
	25820	4·505		36930	4·510		44640	5·750
195° ...	15610	19·42	230° ...	17630	19·43		47840	5·135
	16370	18·16		18540	18·18	270° ...	19880	19·45
	17180	16·91		19560	16·93		20980	18·20
	18070	15·65		20690	15·67		22230	16·95
	19030	14·40		21940	14·42		23610	15·69
	20080	13·16		23350	13·17		24200	14·44
	21200	11·91		24930	11·93		27000	13·19
	22400	10·67		26690	10·69		29080	11·94
	23630	9·440		28690	9·450		31460	10·70
	24880	8·205		30940	8·215		34280	9·460
	26020	6·970		33550	6·975		37690	8·225
	26980	5·740		36570	5·745		41820	6·985
	27650	4·505		40630	4·510		47390	5·755
200° ...	15910	19·42	240° ...	18210	19·44		50900	5·135
	16680	18·17		19170	18·19	280° ...	20410	19·46
	17530	16·92		20250	16·94		21570	18·21
	18450	15·65		21450	15·67		22870	16·95
	19470	14·41		22780	14·42		24340	15·69
	20560	13·16		24300	13·18		26000	14·44
	21740	11·92		25980	11·93		27890	13·19
	23030	10·68		27960	10·69		30070	11·94
	24380	9·445		30120	9·455		32600	10·70
	25790	8·205		32690	8·215		35630	9·465
	27140	6·970		35700	6·980		39280	8·225
	28390	5·740		39310	5·745		43810	6·985
	29500	4·505		41540	5·130		49930	5·755
210° ...	16490	19·42						

Series V.

Temp.	Pressure. millim	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
140° ...	11160	22·63	180° ...	19940	11·37	240° ...	23850	13·49
	11375	21·93	(*cont*)	20470	10·67	(*cont.*)	25750	12·09
	11490	21·58		20970	9·980		27890	10·69
	11595	21·22		21470	9·280		30390	9·290
150° ...	11920	21·93		21900	8·580		31820	8·590
	12170	21·23		22100	8·235		33370	7·895
	12430	20·52	200° ...	14510	21·96		35090	7·200
	12700	19·81		15640	19·84		36940	6·500
	12970	19·10		16970	17·71		39100	5·805
	13260	18·39		18500	15·59		41680	5·105
	13550	17·69		20260	13·48		45050	4·410
	13700	17·30		21570	12·08	260° ...	17440	21·99
160°...	12470	21·94		23010	10·68		18960	19·87
	13030	20·53		24550	9·280		20780	17·74
	13600	19·11		25310	8·585		22960	15·62
	14290	17·69		26100	7·890		25610	13·50
	14620	16·98		26890	7·190		27750	12·10
	14970	16·28		27620	6·495		30260	10·70
	15330	15·58		28320	5·800		33240	9·295
	15680	14·88		28970	5·100		34950	8·595
	16050	14·17		29590	4·405		36850	7·900
170° ...	12990	21·94	220° ...	15500	21·97		39020	7·205
	13600	20·53		16760	19·85		41400	6·505
	14260	19·11		18250	17·72		44270	5·805
	14960	17·70		19990	15·60		47940	5·110
	15740	16·28		22080	13·49		52780	4·410
	16560	14·88		23660	12·08	280° ...	18390	22·01
	17410	13·47		25450	10·69		20030	19·88
	17850	12·77		27480	9·285		22000	17·75
	18290	12·07		28580	8·590		24390	15·63
	18710	11·37		29770	7·890		27350	13·51
	18930	11·02		31010	7·195		29740	12·11
180° ...	13500	21·95		32320	6·500		32600	10·71
	14150	20·54		33710	5·800		36030	9·300
	14860	19·12		35310	5·100		38060	8·600
	15640	17·70		37240	4·405		40260	7·905
	16490	16·29	240° ...	16470	21·98		42890	7·210
	17400	14·88		17870	19·86		45920	6·510
	18390	13·47		19530	17·73		49530	5·810
	19420	12·07		21480	15·61			

Series VI.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
90° ...	3585	76·62	140° ...	9411	29·06	180° ...	12500	24·37
	3678	74·24	(*cont.*)	9993	26·69	(*cont.*)	13480	22·01
	3786	71·86		10640	24·34		14580	19·64
	3895	69·47		11360	21·98		15890	17·28
	4012	67·07	150° ...	4463	74·35		17380	14·91
	4135	64·67		4887	67·17		19070	12·56
	4263	62·26		5400	59·96	200° ...	5084	74·45
100° ...	3813	74·26		6037	52·79		5577	67·26
	4040	69·49		6830	45·63		6186	60·04
	4297	64·68		7498	40·89		6943	52·86
	4432	62·28		8267	36·17		7893	45·70
	4585	59·88		9198	31·43		8697	40·94
	4739	57·49		10410	26·70		9672	36·21
	4910	55·10		11110	24·34		10890	31·47
	5081	52·73		11900	21·98		12430	26·74
	5271	50·35		12770	19·63		13370	24·38
110° ...	3946	74·27		13740	17·26		14460	22·02
	4182	69·51	160° ...	4589	74·37		15740	19·65
	4447	64·70		5032	67·19		17250	17·29
	4749	59·90		5564	59·98		19010	14·92
	5091	55·11		6224	52·81	220° ...	5317	74·48
	5482	50·37		7056	45·64		5847	67·30
	5933	45·59		7734	40·90		6491	60·07
	6185	43·22		8564	36·18		7294	52·89
	6472	40·85		9573	31·44		8314	45·72
120° ...	4079	74·29		10840	26·71		9182	40·96
	4458	67·12		12430	21·99		10220	36·23
	4918	59·91		13400	19·63		11530	31·49
	5472	52·75		14480	17·26		13210	26·75
	6167	45·60		15660	14·90		14250	24·39
	6717	40·86	170° ...	4713	74·39		15470	22·03
	7040	38·50		5172	67·21		16880	19·66
	7376	36·14		5724	59·99		18580	17·30
	7754	33·76		6403	52·82		20620	14·93
	7958	32·59		7272	45·66	240° ...	5562	74·52
130° ...	4206	74·31		7979	40·91		6119	67·34
	4603	67·14		8844	36·19		6807	60·10
	5079	59·93		9910	31·45		7657	52·92
	5665	52·76		11250	26·71		8740	45·74
	6396	45·61		12050	24·36		9658	40·98
	6985	40·87		12960	22·00		10780	36·25
	7689	36·15		14010	19·64		12180	31·50
	8083	33·77		15200	17·27		14010	26·76
	8527	31·41		16540	14·90		15120	24·40
	9012	29·05		18000	12·55		16440	22·04
	9553	26·69	180° ...	4834	74·41		18010	19·67
140° ...	4337	74·33		5302	67·22		19910	17·30
	4751	67·16		5876	60·01		22230	14·94
	5242	59·95		6583	52·83	260° ...	5805	74·56
	5856	52·78		7484	45·67		6389	67·37
	6617	45·62		8222	40·92		7125	60·13
	7243	40·88		9122	36·20		8022	52·94
	7977	36·16		10240	31·46		9160	45·76
	8884	31·42		11650	26·72		10140	41·00

Series VI. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
260° ...	11330	36·26	280° ...	6675	67·40	280° ...	18410	22·06
(*cont.*)	12830	31·52	(*cont.*)	7453	60·16	(*cont.*)	20250	19·69
	14780	26·77		8380	52·97		22520	17 32
	16000	24·41		9608	45·79		25330	14 95
	17430	22·05		10660	41·03		27040	13·76
	19130	19·68		11900	36·28		28980	12·59
	21220	17·31		13490	31·53		31240	11·40
	23760	14·94		15580	26·79		34870	10·21
280° ...	6065	74·60		16870	24·43		37030	9·02

Series VII.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
50° ...	1427	181·60	90° ...	2054	142·05	120° ...	3590	85·72
	1471	175·95	(*cont.*)	2311	125·05	(*cont.*)	4065	74·50
	1514	170·30		2639	108·10		4687	63·30
60° ...	1479	181·65		2913	96·86		5530	52·13
	1524	176·00		3252	85·66	130° ...	1886	176·30
	1570	170·35		3448	80·04		2076	159·25
	1620	164·70		3669	74·44		2313	142·20
	1676	159·00		3923	68·85		2608	125·20
	1732	153·30		4209	63·25		2984	108·20
	1793	147·60	100° ...	1732	176·15		3303	96·96
	1858	141·90		1906	159·15		3698	85·75
	1927	136·25		2120	142·10		4193	74·52
	2001	130·60		2388	125·10		4841	63·32
70° ...	1575	176·05		2727	108·15		5717	52·14
	1679	164·70		3012	96·88	140° ...	1936	176·35
	1793	153·30		3360	85·68		2133	159·30
	1924	141·90		3803	74·46		2377	142·25
	2077	130·60		4368	63·27		2681	125·25
	2253	119·35		5126	52·10		3071	108·25
	2354	113·70	110° ...	1784	176·20		3401	96·98
	2462	108·05		1963	159·20		3808	85·78
	2583	102·45		2185	142·10		4326	74·54
80° ...	1627	176·10		2461	125·10		5000	63·34
	1731	164·75		2816	108·15		5914	52·16
	1851	153·35		3113	96·91	160° ...	2035	176·45
	1986	141·95		3474	85·70		2242	159·40
	2146	130·65		3943	74·48		2503	142·35
	2332	119·40		4534	63·29		2824	125·35
	2552	108·05		5328	52·11		3238	108·30
	2813	96·83	120° ...	1837	176·25		3591	97·03
	2965	91·24		2020	159·20		4023	85·82
	3134	85·64		2251	142·15		4577	74·58
	3321	79·99		2537	125·15		5296	63·37
90° ...	1681	176·10		2902	108·20		6292	52·18
	1848	159·10		3209	96·93			

Series VII. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
180° ...	2132	176·55	200° ..	5888	63·43	250° ...	4979	86·01
	2353	159·50	(*cont.*)	7025	52·23	(*cont.*)	5679	74·76
	2625	142·35	220° ...	2330	176·75		6620	63·51
	2966	125·35		2575	159·70		7211	57·92
	3405	108·35		2877	142·50		7910	52·30
	3775	97·08		3253	125·50		8781	46·68
	4239	85·86		3738	108·45		9871	41·06
	4822	74·62		4156	97·18		11275	35·44
	5590	63·40		4666	85·95	280° ...	2622	177·00
	6654	52·20		5318	74·70		2912	159·90
200° ...	2231	176·65		6176	63·46		3252	142·75
	2463	159·60		7381	52·26		3680	125·70
	2751	142·45	250° ...	2477	176·90		4234	108·65
	3108	125·45		2741	159·80		4712	97·33
	3571	108·40		3068	142·60		5303	86·08
	3962	97·13		3469	125·60		6043	74·81
	4452	85·90		3984	108·55		7065	63·56
	5066	74·66		4431	97·26		8459	52·34

Series VIII.

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
30° ...	776	321·2	60° ..	1857	141·9	90° ...	1152	261·7
	797	312·6	(*cont.*)	1964	133·4	(*cont.*)	1317	227·4
	816	304·0	70° ...	825	347·4		1418	210·3
40° ...	786	329·9		866	330·2		1537	193·2
	827	312·7		965	295·7		1678	176·2
	873	295·5		1085	261·6		1846	159·1
	924	278·5		1239	227·3		2054	142·0
	980	261·4		1334	210·2		2314	124·9
	1044	244·2		1444	193·1	100° ...	822	382·2
	1117	227·1		1574	176·1		860	365·0
50° ...	814	330·0		1732	159·0		947	330·4
	903	295·6		1922	142·0		1054	296·0
	1015	261·4		2164	124·9		1186	261·8
	1082	244·3	80° ...	812	364·8		1357	227·5
	1158	227·2		893	330·2		1462	210·4
	1246	210·1		993	295·8		1584	193·2
	1348	193·0		1118	261·7		1732	176·3
	1468	176·0		1277	227·4		1904	159·2
60° ..	799	347·4		1377	210·3		2120	142·1
	839	330·1		1492	193·2		2389	124·9
	933	295·7		1627	176·2	120° ...	832	399·6
	1049	261·5		1789	159·1		909	365·2
	1199	227·3		1988	142·0		1002	330·5
	1290	210·2		2236	124·9		1113	296·1
	1397	193·1	90° ...	835	364·9		1254	261·9
	1524	176·1		920	330·3		1435	227·6
	1673	159·0		1024	295·9		1547	210·5

Series VIII. (*continued*).

Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.	Temp.	Pressure. millim.	Volume. cub. cm.
120° ...	1678	193·4	180° ...	853	452·3	220° ...	1820	228·2
(*cont.*)	1834	176·4		963	400·2	(*cont.*)	1963	211·0
	2020	159·3		1051	365·7		2130	193·9
	2248	142·1		1159	331·1		2332	176·8
	2536	125·0		1290	296·6		2573	159·7
140° ...	838	417·1		1455	262·4	250° ...	854	523·0
	956	365·4		1677	228·0		915	488·2
	1053	330·7		1800	210·8		1025	435·8
	1172	296·3		1951	193·7		1161	383·6
	1321	262·1		2135	176·7		1340	331·6
	1513	227·7		2358	159·5		1495	297·2
	1632	210·6		2625	142·3		1686	262·8
	1770	193·5		2970	125·2		1934	228·3
	1933	176·5	200° ...	857	470·1		2088	211·2
	2133	159·3		964	417·8		2269	194·0
	2377	142·2		1098	366·0		2480	177·0
	2684	125·1		1209	331·2		2740	159·8
160° ...	847	434·7		1349	296·8	280° ...	876	540·8
	958	382·8		1521	262·5		970	488·5
	1107	330·9		1744	228·1		1084	436·1
	1233	296·4		1880	211·0		1230	384·0
	1388	262·2		2041	193·8		1420	331·9
	1591	227·8		2233	176·7		1583	297·4
	1716	210·7		2466	159·6		1786	263·0
	1861	193·6	220° ...	861	487·8		2049	228·5
	2036	176·6		966	435·4		2213	211·4
	2247	159·4		1093	383·4		2402	194·2
	2503	142·3		1261	331·4		2631	177·1
	2825	125·2		1407	297·0		2907	159·9
				1587	262·6			

The Critical Volume and Density.

It is impossible to determine the critical volume accurately by direct experiment, but it may be calculated from the critical density, which may be ascertained with great accuracy by the method of Cailletet and Mathias (*Compt. Rend.* cii. p. 1202, civ. p. 1563; Mathias, *ibid.* cxv. p. 35).

In the following table the densities (mass of 1 cub. centim.) of liquid and saturated vapour and the mean densities are given at a series of temperatures, together with the mean densities calculated from the formula

$$D = 0·3197 - 0·000454\,t.$$

The close agreement between the calculated and observed mean densities over such a wide range of temperature in this, as in so many other cases, justifies the very small extrapolation to the critical temperature. The mean density at this temperature, 187°·8, calculated from the formula, is 0·2344, and this is the critical density, for, at the critical temperature, the difference between the liquid and saturated vapour ceases to exist. The critical volume of a gram, calculated from the density, is 4·266 cub. centim.

Mean Densities of Liquid and Saturated Vapour.

Temperature.	Density.				
	Liquid.	Saturated Vapour.	Mean.	Calculated.	$\Delta \times 10{,}000$.
10°	·6295	·0016	·3156	·3152	−4
20	·6196	·0024	·3110	·3106	−4
30	·6092	·0033	·3062	·3061	−1
40	·5988	·0045	·3017	·3015	−2
50	·5881	·0060	·2970	·2970	0
60	·5769	·0078	·2924	·2924	0
70	·5656	·0101	·2878	·2879	+1
80	·5540	·0128	·2834	·2834	0
90	·5413	·0162	·2787	·2788	+1
100	·5278	·0203	·2741	·2743	+2
110	·5140	·0251	·2695	·2697	+2
120	·4991	·0311	·2651	·2652	+1
130	·4826	·0383	·2605	·2607	+2
140	·4642	·0473	·2557	·2561	+4
150	·4445	·0583	·2514	·2516	+2
160	·4206	·0729	·2468	·2470	+2
170	·3914	·0932	·2423	·2425	+2
176	·3694	·1103	·2398	·2398	0
180	·3498	·1258	·2378	·2380	+2
183	·3311	·1422	·2366	·2366	0
185	·3142	·1575	·2358	·2357	−1
186	·3028	·1677	·2353	·2352	−1
187	·2857	·1834	·2346	·2348	+2
187·4	·2761	·1951	·2356	·2346	−10
(Critical) 187°·8	......	......	......	·2344	

Critical Volume of a gram......... 4·266 cub. cm.
Critical Molecular Volume......... 306·5 cub. cm.

THEORETICAL CONCLUSIONS.

Relation of Pressure to Temperature at Constant Volume. Isochors.

For the larger volumes of a gram the pressures corresponding to definite volumes were read from the isothermals constructed from the data already given. This method was, however, not practicable in the case of the smaller volumes. Isobars were therefore first constructed, and the temperatures at definite volumes were then read from the isobars. The data from which the isobars were constructed are given in the table below, p. 638.

In the tables which follow (pp. 639–643) the data for two sets of isochors are given, those at smaller volumes from the isobars and those at larger volumes from the isotherms. The pressures read from the isothermals constructed from the data obtained by Thomas and myself by the modified Hofmann's vapour-density method are included in the second set.

Isobars, read from Isothermals.

Pressure in metres.	4	8	12	16	20	24	28	32	36	40	44	48	52	56
Temp.	Volume in cub. centims.													
10°	1·5871	1·5854	1·5838	1·5820	1·5806	1·5790	1·5773	1·5757	1·5742	1·5726	1·5711	1·5696	1·5682	1·5667
15·6	1·6012	1·5994	1·5976	1·5959	1·5941	1·5923	1·5906	1·5889	1·5872	1·5856	1·5839	1·5821	1·5806	1·5791
30	1·6388	1·6366	1·6344	1·6322	1·6300	1·6280	1·6260	1·6240	1·6220	1·6202	1·6184	1·6166	1·6149	1·6131
40	1·6681	1·6655	1·6630	1·6605	1·6581	1·6556	1·6533	1·6510	1·6487	1·6465	1·6444	1·6423	1·6402	1·6382
50	1·6984	1·6953	1·6924	1·6896	1·6868	1·6841	1·6814	1·6788	1·6763	1·6739	1·6715	1·6691	1·6668	1·6645
60	1·7312	1·7277	1·7244	1·7210	1·7179	1·7148	1·7116	1·7086	1·7057	1·7027	1·6999	1·6971	1·6944	1·6916
70	1·7666	1·7625	1·7585	1·7547	1·7510	1·7474	1·7440	1·7405	1·7372	1·7339	1·7306	1·7275	1·7244	1·7212
80	1·8038	1·7992	1·7948	1·7904	1·7861	1·7820	1·7780	1·7740	1·7700	1·7663	1·7625	1·7589	1·7552	1·7516
90	1·8477	1·8420	1·8364	1·8309	1·8255	1·8203	1·8154	1·8106	1·8060	1·8014	1·7974	1·7934	1·7893	1·7749
100	......	1·8896	1·8825	1·8760	1·8695	1·8634	1·8576	1·8516	1·8460	1·8406	1·8356	1·8306	1·8256	1·8008
110	......	1·9417	1·9334	1·9253	1·9176	1·9102	1·9029	1·8961	1·8895	1·8830	1·8771	1·8710	1·8652	1·8596
120	......	2·0037	1·9922	1·9815	1·9713	1·9615	1·9527	1·9445	1·9365	1·9287	1·9215	1·9150	1·9083	1·9015
130	......	......	2·0630	2·0485	2·0350	2·0230	2·0115	2·0005	1·9910	1·9810	1·9715	1·9630	1·9540	1·9463
140	......	......	2·1512	2·1290	2·1105	2·0940	2·0787	2·0650	2·0520	2·0405	2·0287	2·0185	2·0085	1·9987
150	......	......	......	2·2317	2·2035	2·1782	2·1565	2·1385	2·1210	2·1050	2·0912	2·0780	2·0655	2·0537
160	......	......	......	......	2·3285	2·2900	2·2575	2·2305	2·2062	2·1852	2·1657	2·1485	2·1322	2·1180
170	......	......	......	......	2·5252	2·4485	2·3882	2·3450	2·3080	2·2777	2·2512	2·2270	2·2057	2·1872
176	......	......	......	......	......	2·5800	2·4925	2·4315	2·3835	2·3440	2·3112	2·2837	2·2585	2·2362
180	......	......	......	......	......	2·7230	2·5835	2·5005	2·4405	2·3985	2·3550	2·3245	......	......
183	......	......	......	......	......	2·9050	2·6645	2·5590	2·4890	2·4335	2·3912	2·3550	2·3250	2·3000
185	......	......	......	......	......	3·1830	2·7345	2·6050	2·5270	2·4645	2·4165	......	......	......
186	......	......	......	......	......	......	2·7725	......	......	......	......	......	......	......
187·4	......	......	......	......	......	......	2·8360	......	......	......	......	......	......	......
187·8	......	......	......	......	......	......	2·8585	2·6770	2·5790	2·5075	2·4550	2·4115	2·3745	2·3445
190	......	......	......	......	......	......	......	2·7440	2·6260	2·5480	2·4880	2·4405	2·4000	2·3645
195	......	......	......	......	......	......	......	......	2·7580	2·6460	2·5700	2·5095	2·4610	2·4200
200	......	......	......	......	......	......	......	......	2·9355	2·7700	2·6650	2·5900	2·5305	2·4845
205	......	......	......	......	......	......	......	......	......	......	2·7790	2·6815	2·6110	......
210	......	......	......	......	......	......	......	......	......	......	2·9195	2·7930	2·6990	2·6200
220	......	......	......	......	......	......	......	......	......	......	......	......	2·9145	2·8045

Isochors, read from Isobars.

Pressure in metres.	4	8	12	16	20	24	28	32	36	40	44	48	52	56
Volume.	Temperature.													
	°	°	°	°	°	°	°	°	°	°	°	°	°	°
1·58	......	......	......	......	9·75	10·45	11·15	11·90	12·50	13·15	13·95	14·65	15·35	16·05
1·60	15·2	15·95	16·65	17·45	18·1	18·9	19·65	20·4	21·05	21·8	22·55	23·35	24·0	24·75
1·65	33·9	34·7	35·5	36·4	37·15	38·0	38·9	39·75	40·5	41·35	42·15	42·9	43·7	44·55
1·70	50·5	51·45	52·4	53·35	54·3	55·25	56·2	57·15	58·1	59·05	60·0	60·95	61·9	62·95
1·75	65·4	66·5	67·55	68·65	69·75	70·7	71·85	72·95	74·0	75·05	76·1	77·25	78·35	79·45
1·80	78·95	80·1	81·2	82·45	83·65	84·75	85·95	87·2	88·3	89·6	90·7	91·8	93·0	94·3
1·85	......	91·8	93·0	94·45	95·7	97·0	98·4	99·75	101·0	102·35	103·7	105·0	106·3	107·7
1·90	......	102·2	103·6	105·05	106·5	107·9	109·35	110·85	112·3	113·8	115·3	116·75	118·25	119·75
1·95	......	111·3	112·95	114·6	116·2	117·8	119·45	121·0	122·6	124·2	125·75	127·35	129·1	130·7
2·0	......	119·55	121·15	122·9	124·75	126·65	128·5	129·95	131·6	133·3	135·0	136·8	138·55	140·2
2·1	......	......	134·55	136·7	138·7	140·75	142·95	145·0	147·05	149·15	151·15	153·3	155·3	157·5
2·2	......	......	......	147·25	149·7	152·2	154·65	157·0	159·3	161·7	164·25	166·75	169·15	171·6
2·3	......	......	......	155·25	158·0	160·75	163·5	166·4	169·3	172·1	174·95	177·7	180·45	183·2
2·4	......	......	......	......	164·45	167·45	170·7	173·8	177·2	180·5	183·7	186·8	190·0	193·2
2·5	......	......	......	......	169·15	172·65	176·4	180·0	183·7	187·3	190·9	194·3	198·0	201·3
2·6	......	......	......	......	172·3	176·75	180·65	184·75	188·85	192·75	196·7	200·6	204·3	208·7
2·7	......	......	......	......	......	179·55	184·15	188·7	193·0	197·3	201·6	205·85	210·05	214·7
2·8	......	......	......	......	......	181·55	186·7	191·4	196·3	201·0	205·75	210·25	215·0	219·75

Isochors, read from Isothermals.

Vol....	2·4	2·5	2·6	2·7	2·8	2·9	3·0	3·2	3·4	3·6	3·8
Temp.	Pressures.										
170°	27060	21020	...	...	...	...	...	...	...	...	...
176	34520	27580	23360	21060	...	...	...	...	...	...	...
180	39400	32060	27380	24460	22830	...	...	...	...	...	...
183	43120	35280	30260	27050	25130	24010	23360	...	...	...	...
185	45680	37480	32280	28850	26710	25420	24660	...	...	...	...
187·8	49080	40560	34980	31270	28940	27420	26460	25490	25130	25050	25030
190·0	52000	43140	37280	33270	30730	29070	27860	26770	26270	26070	25960
195	...	48820	42320	37860	34880	32850	31460	29780	28940	28460	28190
200	...	54560	47480	42490	39100	36680	35010	32870	31660	30950	30480
205	...	...	...	47140	43270	40560	38550	35990	34430	33510	32820
210	...	...	...	51990	47700	44510	42160	39090	37260	36020	35140
220	...	...	...	...	...	52430	49630	45570	42940	41170	39910
230	...	...	...	...	...	...	...	52100	48860	46460	44680
240	...	...	...	..	...	...	...	...	..	51890	49690

Isochors, read from Isothermals.

Vol....	4·0	Approx. Crit. 4·3	4·6	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5
Temp.	Pressures.										
180°	...	...	...	...	...	...	...	...	...	22230	21950
183	...	...	...	...	...	...	...	...	23090	22800	22490
185	...	...	...	...	...	...	23960	23770	23510	23200	22860
187·8	25020	25010	25000	24990	24940	24840	24660	24400	24070	23710	23330
190·0	25910	25860	25810	25760	25620	25420	25180	24880	24530	24110	23700
195	28000	27780	27650	27430	27130	26790	26420	26010	25570	25080	24590
200	30140	29730	29430	29060	28610	28150	27630	27100	26570	26010	25430
205	32310	31730	31260	30740	30070	29460	28840	28220	...	...	...
210	34460	33680	33070	32350	31540	30760	30010	29280	28530	27820	27110
220	38890	37640	36640	35580	34420	33350	32340	31380	30460	29600	28750
230	43280	41590	40280	38850	37290	35920	34680	33500	32400	31370	30400
240	47900	45770	44010	42130	40170	38500	37000	35610	34330	33140	32030
250	52360	49770	47740	45440	43030	41020	39270	37680	36240	34900	33660
260	...	53800	51380	48680	45890	43530	41480	39690	38080	36600	35220
270	...	...	...	51910	48750	46070	43780	41770	39980	38360	36860
280	...	...	...	...	51540	48580	46000	43750	41770	40000	38380

Isochors, read from Isothermals.

Vol. …	9·0	9·5	10·0	11	12	13	14	15	16	17	18
Temp.	Pressures.										
150°	…	…	…	…	…	…	…	…	…	…	13430
160	…	…	…	…	…	…	16160	15620	15110	14620	14140
170	…	…	…	18950	18330	17710	17080	16490	15900	15330	14815
176	…	20700	20390	19720	19020	18330	18630	17000	16370	15780	15210
180	21630	21300	20950	20210	19470	18730	18010	17320	16670	16040	15470
183	22130	21770	21380	20590	19800	19030	18280	17570	16920	16270	15680
185	22490	22090	21690	20870	20040	19250	18480	17750	17060	16420	15810
187·8	22930	22500	22040	21160	20300	19500	18720	17980	17260	16600	15990
190·0	23250	22820	22360	21440	20560	19710	18910	18150	17440	16780	16130
195	24080	23570	23060	22060	21100	20200	19350	18550	17810	17110	16470
200	24870	24310	23760	22680	21670	20710	19810	18970	18180	17460	16800
210	26430	25770	25110	23880	22720	21670	20670	19780	18930	18140	17430
220	27950	27170	26430	25050	23770	22620	21560	20570	19650	18830	18050
230	29480	28600	27750	26200	24830	23550	22400	21350	20370	19500	18690
240	30990	30010	29090	27400	25890	24500	23250	22130	21110	20180	19330
250	32510	31430	30410	28570	26900	25460	24120	22940	21840	20850	19940
260	33970	32790	31690	29700	27940	26370	24970	23700	22560	21510	20540
270	35460	34180	33000	30870	28980	27300	25810	24480	23260	22160	21150
280	36920	35530	34240	31950	29970	28190	26620	25220	23970	22810	21770

Isochors, read from Isothermals.

Vol. …	19	20	22	24	26	28	30	33	36	40	45
Temp.	Pressures.										
110°	…	…	…	..	…	…	…	…	…	6570	5995
120	…	…	…	…	…	…	…	7890	7400	6830	6235
130	…	…	…	…	…	9250	8825	8220	7705	7100	6465
140	…	…	11355	10745	10175	9665	9195	8555	8000	7365	6700
150	13020	12630	11890	11215	10600	10035	9530	8870	8295	7625	6920
160	13685	13260	12440	11720	11050	10465	9930	9205	8595	7880	7140
170	14310	13835	12960	12180	11480	10845	10275	9530	8880	8130	7360
176	14680	…	…	…	…	…	…	…	…	…	…
180	14920	14405	13480	12650	11900	11225	10635	9855	9160	8380	7575
183	15100	…	…	…	…	…	…	…	…	…	…
185	15230	…	…	…	…	…	…	…	…	…	…
187·8	15400	…	…	…	…	…	…	…	…	…	…
190·0	15540	14985	…	…	…	…	…	…	…	…	…
195	15870	…	…	…	…	…	…	…	…	…	…
200	16150	15550	14480	13525	12700	11980	11325	10460	9705	8870	8000
210	16760	16110	…	…	…	…	…	…	…	…	…
220	17350	16690	15480	14445	13525	12730	12025	11075	10275	9380	8440
230	17950	17250	…	…	…	…	…	…	…	…	…
240	18530	17800	16480	15340	14360	13475	12705	11700	10845	9875	8875
250	19100	…	…	…	…	…	…	…	…	…	…
260	19670	18880	17470	16210	15140	14210	13390	12330	11425	10380	9305
270	20250	…	…	…	…	…	…	…	…	…	…
280	20820	19970	18450	17120	15990	14995	14095	12960	11990	10920	9775

Isochors, read from Isothermals.

Vol. ...	50	60	70	80	90	100	120	140	160	180	200
Temp.	Pressures.										
50°	...	...	...	...	...	...	...	...	...	1438	1305
60	...	...	...	...	...	...	...	1880	1665	1491	1354
70	...	...	...	...	...	2633	2240	1947	1720	1544	1400
80	...	...	...	3321	3000	2738	2315	2015	1780	1594	1443
90	...	...	3865	3452	3110	2835	2400	2081	1837	1643	1489
100	5295	4575	4015	3565	3215	2932	2480	2152	1897	1695	1532
110	5510	4745	4150	3698	3327	3030	2558	2217	1953	...	...
120	5720	4910	4295	3820	3440	3117	2637	2283	2009	1796	1622
130	5930	5080	4435	3938	3537	3212	2711	2348	2062	...	...
140	6135	5240	4570	4055	3645	3303	2790	2413	2120	1896	1714
150	6330	5400	4715	...	...	...	...	...	...	...	...
160	6525	5560	4850	4295	3850	3492	2943	2545	2234	1995	1805
170	6725	5725	4990	...	...	...	...	...	...	...	...
180	6920	5880	5110	4522	4052	3667	3093	2666	2345	2096	1894
200	7290	6185	5375	4757	4257	3855	3240	2800	2458	2194	1981
220	7675	6500	5635	4993	4475	4043	3393	2926	2566	2290	2066
240	8060	6820	5905	...	...	...	...	...	...	...	...
250	...	...	...	5325	4765	4310	3622	3130	2739	2435	2200
260	8455	7145	6165	...	...	...	...	...	...	...	...
280	8850	7460	6450	5685	5085	4588	3848	3320	2907	2584	2334

Isochors, read from Isothermals.

Vol. ...	230	260	300	350	400	500	600	700	800	900	1000
Temp.	Pressures.										
10·75°	...	...	...	...	...	...	398	342·5	300	268	241·5
30	...	...	...	719	633·5	509	426	366·5	322	286·5	258·5
40	1105	985	860	743·5	654	526	440·5	380	333·5	296·5	267
50	1145	1020	890	769	675·5	544	454·5	391·5	344	305·5	275
60	1186	1054	917	795	699	561·5	470·5	404	355	316	284·5
70	1225	1092	952	820	720	580	484·5	416·5	365·5	325	293·5
80	1262	1124	979	844	743·5	596·5	500	429·5	376	335	302
90	1301	1158	1010	869	764·5	615	514	441·5	387·5	345	311
100	1343	1194	1038	895	787	634	528·5	454	398·5	354·5	319·5
110	...	...	...	...	809·5	650	543·5	467	409·5	364·5	328·5
120	1420	1262	1097	947	831	670	559·5	479·5	420·5	374	337
130	...	...	...	...	854·5	686	574	493	431·5	384	346
140	1497	1332	1156	995	876·0	704·5	588·5	505	443·5	395	355
150	...	...	...	...	899·5	723·5	604·5	518·5	454	403·5	363·5
160	1576	1400	1216	1046	916	...	...	...	...	...	...
180	1654	1467	1275	1095	964	...	...	...	...	...	...
200	1728	1535	1334	146	1005	...	...	...	...	...	...
220	1806	1603	1394	194	1047	...	...	...	...	...	...
250	1921	1706	1481	1272	1114	...	...	...	...	...	...
280	2036	1806	1568	1349	1182	...	...	...	...	...	...

Isochors, read from Isothermals.

Vol. ...	1200	1400	1600	1800	2000	2300	2600	3000	3500	4000
Temp.	Pressures.									
10·75°	202·0	...	...	...	...	...	...	...	...	...
11·0	202·0	173·5	151·8	135·1	121·8	106·2	94·2	81·6	70·0	61·3
16·3	205·5	177·0	154·9	137·8	124·0	108·1	95·8	83·0	71·4	62·4
30	215·8	185·5	162·4	144·4	130·1	113·5	100·6	87·3	74·7	65·3
40	223·0	191·5	168·0	149·8	134·8	117·3	104·1	90·4	77·5	67·7
50	230·0	197·5	173·3	154·3	139·2	121·0	107·2	93·3	79·9	69·8
60	237·3	204·2	178·7	158·9	143·1	124·7	110·3	96·0	82·2	71·8
70	245·0	210·0	184·0	163·4	147·5	128·7	113·8	98·8	84·8	74·2
80	251·6	215·7	189·4	168·4	151·8	132·1	117·2	101·9	87·3	76·2
90	259·2	223·5	195·3	173·9	156·6	136·1	120·7	105·1	89·9	78·5
100	266·7	229·7	200·9	179·0	160·7	140·0	124·3	108·0	92·4	80·4
110	273·5	...	...	...	...	...	...	...	...	...
120	280·5	...	...	...	...	...	...	...	...	...
130	288·5	...	...	...	...	...	...	...	...	...
140	296·0	...	...	...	...	...	...	...	...	...
150	303·0	...	...	...	...	...	...	...	...	...

The values of $\frac{dp}{dt}$ (b in the equation $p=b\mathrm{T}-a$) have been calculated from the data given in the preceding tables, and as they are not quite constant at all volumes it seems necessary to give them in detail so as to indicate the nature of the variations. This, however, has not been done for volumes below 2·4 cub. centim., for which the values of $\frac{dp}{dt}$ were obtained from the isobars, because the deviations are within the limits of experimental error.

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol. …	2·4	2·5	2·6	2·7	2·8	2·9	3·0	3·2	3·4	3·6	3·8
Temp.											
170°											
176	1243	1093	…	…	…	…	…	…	…	…	…
180	1220	1120	1005	850	…	…	…	…	…	…	…
183	1240	1073	960	863	767	…	…	…	…	…	…
185	1280	1100	1010	900	790	705	650	…	…	…	…
187·8	1214	1100	964	864	796	714	643	…	…	…	…
190	1327	1173	1045	909	814	750	636	577	518	464	423
195	…	1136	1008	918	830	756	720	602	534	478	446
200	…	1148	1032	926	844	766	710	618	544	498	458
205	…	…	…	930	834	776	708	624	554	512	468
210	…	…	…	970	886	790	722	620	566	502	464
220	…	…	…	…	…	792	747	648	568	515	477
230	…	…	…	…	…	…	…	653	592	529	477
240	…	…	…	…	…	…	…	…	…	543	501

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol. …	4·0	4·3	4·6	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5
Temp.											
180°											
183	…	…	…	…	…	…	…	…	…	190	180
185	…	…	…	…	…	…	…	…	210	200	185
187·8	…	…	…	…	…	…	250	225	200	182	168
190	405	386	368	350	309	264	236	218	209	182	167
195	418	384	368	334	302	274	248	226	208	194	198
200	428	390	356	326	296	272	242	222	200	186	168
205	434	400	366	336	292	262	242	224	196	181	168
210	430	390	362	322	294	260	234	212			
220	443	396	357	323	288	259	233	210	193	178	164
230	439	395	364	327	287	257	234	212	194	177	165
240	462	418	373	328	288	258	232	211	193	177	163
250	446	400	373	331	287	252	227	207	191	176	163
260	…	403	364	324	286	251	221	201	184	170	156
270	…	…	…	323	286	254	230	208	190	176	164
280	…	…	…	…	279	251	222	198	179	164	152

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol. ...	9·0	9·5	10	11	12	13	14	15	16	17	18
Temp.											
150°											
	...	...	...	...	...	...	...	...	...	...	71
160											
	...	...	...	...	...	...	92	87	79	71	67·5
170											
	...	...	...	126	114	102	93	83	77	71	65·5
180											
	172	158	148	132	114	104	94	86	78	76	68
185											
	152	146	134	114	104	92	86	80	76	72	64
190											
	166	150	140	124	108	98	88	80	74	66	68
195											
	158	148	140	124	114	102	92	84	74	70	66
200											
	156	146	135	120	105	96	86	81	75	68	63
210											
	152	140	132	117	105	95	89	79	72	69	62
220											
	153	143	132	115	106	93	84	78	72	67	64
230											
	151	141	134	120	106	95	85	78	74	68	64
240											
	152	142	132	117	101	96	87	81	73	67	61
250											
	146	136	128	113	104	91	85	76	72	66	60
260											
	149	139	131	117	104	93	84	78	70	65	61
270											
	146	135	124	108	99	89	81	74	71	65	62
280											

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol....	19	20	22	24	26	28	30	33	36	40	45
Temp.											
110°											
	...	...	...	...	...	...	...	...	...	26	24
120											
	...	...	...	...	...	...	...	33	30·5	27	23
130											
	...	...	...	...	...	41·5	37	33·5	29·5	26·5	23·5
140											
	...	...	53·5	47	42·5	37	33·5	31·5	29·5	26	22
150											
	66·5	63	55	50·5	45	43	40	33·5	30	25·5	22
160											
	62·5	57·5	52	46	43	38	34·5	32·5	28·5	25	22
170											
	61	57	52	47	42	38	36	32·5	28	25	21·5
180											
	62	58									
190			50	43·7	45	37·8	34·5	30·2	27·8	24·5	21·2
	61	56·5									
200											
	61	56									
210			50	46	41·2	37·5	35	30·8	28·5	25·5	22
	59	58									
220											
	60	56									
230			50	44·8	41·8	37·2	34	31·2	28·5	24·8	21·8
	58	55									
240											
	57										
250		54	49·5	43·5	39	36·8	34·8	31·5	29	25·2	21·5
	57										
260											
	58										
270		54·5	49	45·5	42·5	39·7	35·2	31·5	28·2	27	23·5
	57										
280											

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol....	50	60	70	80	90	100	120	140	160	180	200
Temp.											
50°											
	...	...	...	...	...	...	...	...	...	5·3	4·9
60											
	...	...	...	...	...	...	...	6·7	5·5	5·3	4·6
70											
	...	...	...	...	...	10·5	7·5	6·8	6·0	5·0	4·3
80											
	...	...	...	13·1	11·0	9·7	8·5	6·6	5·7	4·9	4·6
90											
	...	...	15·0	11·3	10·5	9·7	8·0	7·1	6·0	5·2	4·3
100											
	21·5	17·0	13·5	13·3	11·2	9·8	7·8	6·5	5·6		
110										5·05	4·5
	21·0	16·5	14·5	12·2	11·3	9·7	7·9	6·6	5·6		
120											
	21·0	17·0	14·0	11·8	9·7	9·5	7·4	6·5	5·3		
130										5·0	4·6
	20·5	16·0	13·5	11·7	10·8	9·1	7·9	6·5	5·8		
140											
	19·5	16·0	14·5								
150				12·0	10·25	9·45	7·65	6·6	5·7	4·95	4·55
	19·5	16·0	13·5								
160											
	20·0	16·5	14·0								
170				11·35	10·1	8·75	7·5	6·05	5·55	5·05	4·45
	19·5	15·5	12·0								
180											
	18·5	15·25	13·25	11·75	10·25	9·4	7·35	6·7	5·65	4·9	4·35
200											
	19·25	15·75	13·0	11·8	10·9	9·4	7·65	6·3	5·4	4·8	4·25
220											
	19·25	16·0	13·5								
240				11·07	9·67	8·9	7·63	6·8	5·77	4·83	4·47
	19·75										
250	...	16·25	13·0								
260				12·0	10·67	9·25	7·53	6·33	5·6	4·97	4·47
	19·75	15·75	14·25								
280											

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol.... Temp.	230	260	300	350	400	500	600	700	800	900	1000
10°·75											
11							1·45	1·25	1·14	·96	·88
16·3											
30	...	...	...	2·45	2·05	1·7	1·45	1·35	1·15	1·0	·85
40	4·0	3·5	3·0	2·55	2·15	1·8	1·4	1·15	1·05	·9	·9
50	4·1	3·4	2·7	2·6	2·35	1·75	1·6	1·25	1·1	1·05	·95
60	3·9	3·8	3·5	2·5	2·1	1·85	1·4	1·25	1·05	·9	·9
70	3·7	3·2	2·7	2·4	2·35	1·65	1·55	1·3	1·05	1·0	·85
80	3·9	3·4	3·1	2·5	2·1	1·85	1·4	1·2	1·15	1·0	·9
90	4·2	3·6	2·8	2·6	2·25	1·9	1·45	1·25	1·1	·95	·85
100					2·25	1·6	1·5	1·3	1·1	1·0	·9
110	3·85	3·4	2·95	2·6	2·15	2·0	1·6	1·25	1·1	·95	·85
120					2·35	1·6	1·45	1·35	1·1	1·0	·9
130	3·85	3·5	2·95	2·4	2·15	1·85	1·45	1·2	1·2	1·1	·9
140					2·35	1·9	1·6	1·35	1·05	·85	·85
150	3·95	3·4	3·0	2·55	1·65	...	...	...	...	...	...
160	3·9	3·35	2·95	2·45	2·4	...	...	...	...	...	...
180	3·7	3·4	2·95	2·55	2·05	...	...	...	...	...	...
200	3·9	3·4	3·0	2·4	2·1	...	...	...	...	...	...
220	3·83	3·43	2·9	2·6	2·23	...	...	...	...	...	...
250	3·83	3·33	2·9	2·57	2·27	...	...	...	...	...	...
280											

Values of $\frac{dp}{dt}$ $(=b)$ from Isochors.

Vol. ...	1200	1400	1600	1800	2000	2300	2600	3000	3500	4000
Temp.										
10°·75										
11·0	·64									
16·3		·66	·58	·51	·42	·36	·30	·26	·26	·21
30	·75	·62	·55	·50	·45	·39	·35	·31	·24	·21
40	·72	·60	·56	·54	·47	·38	·35	·31	·28	·24
50	·70	·60	·53	·45	·44	·37	·31	·29	·24	·21
60	·73	·67	·54	·46	·39	·37	·31	·27	·23	·20
70	·77	·58	·53	·45	·44	·40	·35	·28	·26	·24
80	·66	·57	·54	·50	·43	·34	·34	·31	·25	·20
90	·76	·78	·59	·55	·48	·40	·35	·32	·26	·23
100	·75	·62	·56	·51	·41	·39	·36	·29	·25	·19
110	·68	...	...	...	...	...	...	...	...	...
120	·70	...	...	...	...	...	...	...	...	...
130	·80	...	...	...	...	...	...	...	...	...
140	·75	...	...	...	...	...	...	...	...	...
150	·70	...	...	...	...	...	...	...	...	...

It will be seen from the preceding tables that the values of $\frac{dp}{dt}$ $(=b)$ are nearly but not quite constant. At volumes lower than 4·6 cub. centim. (the critical volume of a gram $=4·266$ cub. centim.) the values of b increase with rise of temperature, whilst at greater volumes (up to about 400 cub. centim.) they diminish. At still larger volumes they appear to be constant, at any rate the deviations are within the limits of experimental error.

These deviations of b from constancy appear to be far too regular to be attributed to experimental error, and the results seem to confirm the conclusion arrived at by Amagat in the case of the substances examined by him, that the values of b are not absolutely constant.

It is noteworthy that with isopentane the isochor for a volume very slightly higher than the critical volume is straight, whilst those on either side are slightly curved in opposite directions.

It is also noticeable that the variations in the values of b diminish as the temperature rises, and, indeed, that at volumes higher than 30 cub. centim. they practically disappear at the higher temperatures.

This also agrees with Amagat's conclusions from his observations with carbon dioxide, ethylene, and other gases ("Mémoires sur l'élasticité et la dilatabilité des Fluides jusqu' aux très hautes Pressions," *Ann. Chim. Phys.* 6th Series, vol. xxix. p. 67) :—"Il parait résulter de l'ensemble de ces résultats que les variations du coefficient de pression avec la température, *toujours très petites*, s'annulent aux températures suffisamment élevées et probablement à toutes les températures, sous des pressions suffisantes ; c'est bien ce que paraissent montrer les résultats relatifs à ceux des gaz qui, dans les limites de température de ce travail, sont déjà beaucoup au-dessus de leur température critique."

The temperatures and pressures at the volumes given in the tables were mapped, and straight lines drawn to pass as well as possible through the points. From these straight lines the values of b were obtained, and they are given in the following table (pp. 650, 651). As the values of b tend to become constant at high temperatures, they have also been calculated for volumes from 2·4 to 400 cub. centim. from the observations at the three highest temperatures, and these are also given.

At lower volumes than 2·4 cub. centim. the isochors were obtained indirectly from the isobars, and at higher volumes than 400 cub. centim. the variations are within the limits of experimental error.

The values of b cannot well be mapped against the volume, but I have adopted the suggestion of Rose-Innes and plotted the values of $\frac{10000}{bv}$ against $v^{-1/3}$ (fig. 3, p. 652).

At the largest volumes the value of $\frac{10000}{bv}$ becomes very nearly constant and agrees closely with that (11·6) calculated from the molecular weight of isopentane.

Volume of a gram in cub. centim.	b. From drawn Isochors.	b. From observations at three highest temperatures.	$\frac{10000}{bv}$. From drawn Isochors.	$\frac{10000}{bv}$. From observations at three highest temperatures.
1·58	5711	......	1·108	......
1·6	5450	......	1·147	......
1·65	4823	......	1·257	......
1·7	4202	......	1·400	......
1·75	3712	......	1·540	......
1·8	3390	......	1·639	......
1·85	3014	......	1·794	......
1·9	2734	......	1·925	......
1·95	2475	......	2·072	......
2·0	2309	......	2·165	......
2·1	1914	......	2·487	......
2·2	1644	......	2·764	......
2·3	1425	......	3·051	......
2·4	1238	1274	3·365	3·27
2·5	1111	1152	3·602	3·47
2·6	998·5	1028	3·851	3·74
2·7	913·0	942	4·056	3·93
2·8	834·5	855	4·279	4·18
2·9	763·0	786	4·520	4·39
3·0	704·5	726	4·731	4·59
3·2	627·0	640	4·986	4·88
3·4	557·0	575	5·281	5·12
3·6	509·5	529	5·455	5·25
3·8	468·0	485	5·507	5·43
4·0	436·0	449	5·733	5·57
4·3	397·0	407	5·859	5·71
4·6	363·9	370	5·973	5·88
5·0	327·1	326	6·114	6·14
5·5	288·7	284	6·298	6·40
6·0	256·8	252	6·489	6·61
6·5	232·1	224	6·628	6·87
7·0	210·5	202	6·786	7·07
7·5	192·6	184	6·925	7·25
8·0	177·4	170	7·046	7·35
8·5	164·3	157	7·195	7·49
9·0	152·3	147	7·294	7·56
9·5	141·8	137	7·424	7·68
10	132·6	128	7·541	7·81
11	118·0	112·7	7·705	8·07
12	105·3	102·3	7·917	8·15
13	95·11	91·0	8·088	8·45
14	86·67	83·3	8·258	8·58
15	79·37	76·0	8·400	8·77
16	73·86	71·0	8·463	8·80
17	68·26	65·3	8·618	9·01
18	63·31	61·0	8·698	9·11
19	59·63	57·3	8·835	9·18
20	56·36	54·5	8·872	9·18
22	50·62	49·5	8·979	9·18
24	45·31	44·6	9·196	9·34
26	41·30	41·1	9·314	9·36
28	38·11	37·9	9·372	9·42
30	35·20	34·7	9·470	9·61
33	31·77	31·4	9·539	9·65
36	28·57	28·6	9·722	9·71

Table (*continued*).

	b.		$\frac{10000}{bv}$.	
Vol. of gram in c.c.	From drawn Isochors.	Obs. at 3 highest temps.	From drawn Isochors.	Obs. at 3 highest temps.
40	25·48	25·7	9·813	9·73
45	22·03	22·3	10·09	9·97
50	19·49	19·6	10·26	10·21
60	15·94	16·0	10·46	10·42
70	13·56	13·6	10·53	10·50
80	11·92	11·62	10·49	10·76
90	10·47	10·41	10·61	10·67
100	9·31	9·18	10·74	10·89
120	7·66	7·60	10·87	10·97
140	6·54	6·48	10·92	11·02
160	5·64	5·59	11·07	11·18
180	4·97	4·87	11·18	11·41
200	4·45	4·40	11·24	11·36
230	3·887	3·85	11·18	11·29
260	3·427	3·39	11·22	11·35
300	2·957	2·93	11·27	11·38
350	2·521	2·52	11·33	11·34
400	$\begin{cases} 2·188 \\ 2·222 \end{cases}$	2·20	$\begin{cases} 11·43 \\ 11·25 \end{cases}$	11·36 ......
500	1·792	......	11·16	......
600	1·485	......	11·22	......
700	1·261	......	11·33	......
800	1·095	......	11·42	......
900	0·977	......	11·37	......
1000	0·881	......	11·35	......
1200	0·727	......	11·45	......
1400	0·626	......	11·41	......
1600	0·549	......	11·37	......
1800	0·483	......	11·51	......
2000	0·437	......	11·45	......
2300	0·377	......	11·53	......
2600	0·332	......	11·58	......
3000	0·292	......	11·40	......
3500	0·251	......	11·39	......
4000	0·216	......	11·58	......

A curve drawn through the points obtained from the drawn isochors shows a decided hump in the neighbourhood of the critical volume, and, in this respect, resembles that constructed from the data obtained by Ramsay and myself with ether. With the values of $\frac{10000}{bv}$ calculated from the observations at the highest temperatures the hump becomes far less marked but does not disappear; with the values derived from the observations at the lowest temperatures it would be greatly exaggerated.

It is possible that at still higher temperatures the curve might become quite smooth, but unfortunately above 280°

Fig. 3.

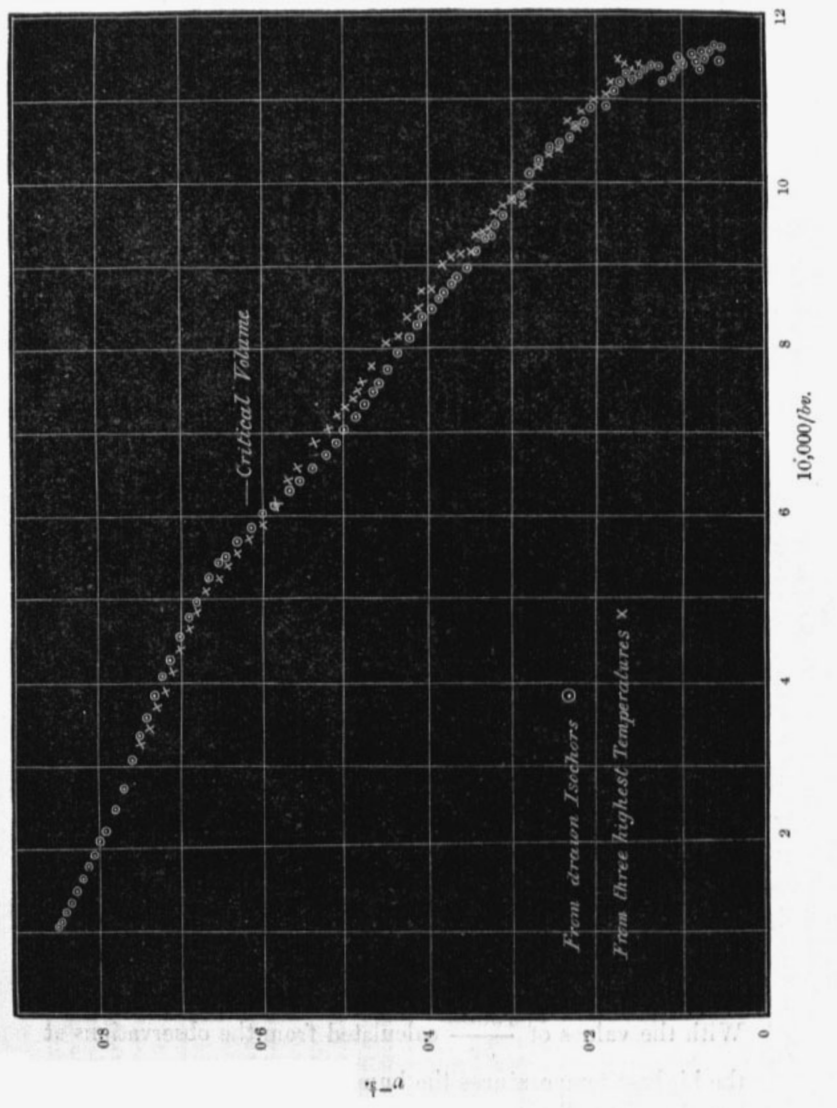
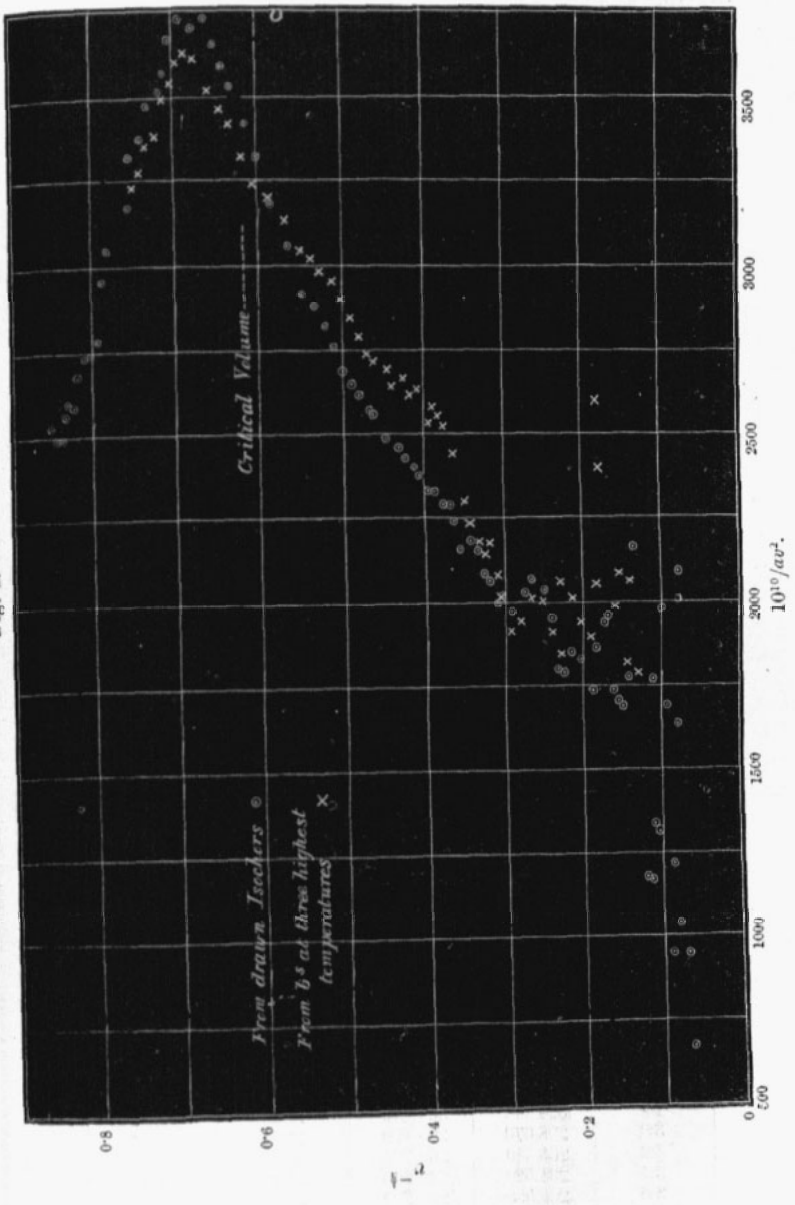

—Critical Volume
From drawn Isochors ⊙
From three highest Temperatures ×
10,000/bv.
0
2
4
6
8
10
12
0·2
0·4
0·6
0·8

Fig. 4.


Critical Volume
From drawn Isochers
From b's at three highest temperatures
$10^{10}/av^2$.
500
1000
1500
2000
2500
3000
3500
0·8
0·6
0·4
0·2

the vapour-pressure of mercury becomes too great to allow of accurate observations being made.

The values of a in the equation $p=bT-a$ were ascertained from the drawn isochors, and are given in the table below; also the values of a calculated from those of b derived from the observations at the three highest temperatures. In the latter case, whilst the slope of the isochor depends only on the results obtained at the highest temperatures, the whole of the observations were taken into account in determining its position, and therefore the value of a.

In mapping the values of a it was found best, as suggested by Rose-Innes, to plot $\frac{10^{10}}{av^2}$ against $v^{-\frac{1}{3}}$. The curve is given in fig. 4 (p. 653), and the data in the following table.

It will be seen that a maximum is reached at about volume 3·2, and in this respect also the isopentane results show a strong resemblance to those with ether, the maximum for that substance being at about the same volume.

	a.		$\frac{10^{10}}{av^2}$.	
Volume of a gram in cub. centim.	From drawn Isochors.	From b's from three highest temperatures.	From drawn Isochors.	From b's from three highest temperatures.
1·58	1,595,000	......	2511	......
1·6	1,566,800	......	2493	......
1·65	1,476,000	......	2489	......
1·7	1,355,200	......	2553	......
1·75	1,252,300	......	2607	......
1·8	1,189,000	......	2596	......
1·85	1,091,200	......	2678	......
1·9	1,017,400	......	2723	......
1·95	943,300	......	2788	......
2·0	898,400	......	2783	......
2·1	768,200	......	2952	......
2·2	676,700	......	3053	......
2·3	594,300	......	3181	......
2·4	521,550	537,640	3329	3229
2·5	471,000	489,930	3397	3266
2·6	425,050	438,550	3480	3373
2·7	389,450	402,590	3522	3407
2·8	355,650	365,010	3586	3494
2·9	324,030	334,850	3670	3551
3·0	298,070	308,120	3728	3606
3·2	263,340	269,700	3708	3621
3·4	231,520	240,200	3736	3601
3·6	209,590	219,230	3682	3520
3·8	190,690	198,930	3632	3481
4·0	175,900	182,310	3553	3428
4·3	157,880	162,890	3426	3320
4·6	142,630	145,690	3313	3244
5·0	125,630	125,150	3184	3196
5·5	107,960	105,650	3062	3129

	a.		$10^{10}/av^2$.	
Vol. of gram in c.c.	From drawn Isochors.	From b's fr. 3 highest temps.	From drawn Isochors.	From b's fr. 3 highest temps.
6	93,330	90,940	2976	3055
6·5	82,150	78,160	2881	3028
7	72,485	68,240	2816	2991
7·5	64,560	60,315	2754	2947
8	57,940	54,311	2697	2877
8·5	52,322	48,787	2645	2837
9	47,219	44,599	2615	2768
9·5	42,945	40,452	2580	2739
10	39,001	36,754	2564	2721
11	33,192	30,732	2490	2689
12	28,158	26,590	2466	2612
13	24,310	22,320	2434	2651
14	21,211	19,621	2405	2600
15	18,619	16,998	2386	2615
16	16,790	15,427	2327	2532
17	14,864	13,406	2328	2581
18	13,488	12,120	2288	2547
19	12,073	10,995	2295	2519
20	11,149	10,257	2242	2437
22	9511	8982	2172	2300
24	7912	7597	2194	2285
26	6848	6759	2160	2189
28	6070	5978	2101	2139
30	5345	5114	2079	2173
33	4592	4419	2000	2078
36	3814	3830	2023	2015
40	3174	3284	1969	1903
45	2423	2550	2038	1937
50	1935	1986	2067	2014
60	1358	1388	2046	2001
70	1043	1065	1957	1916
80	874	755	1788	2070
90	693	670	1782	1843
100	542	496	1845	2016
120	381	357	1823	1945
140	292	270	1747	1889
160	210	189	1860	2067
180	160	119	1930	2594
200	128	105	1950	2381
230	109	95	1730	1990
260	87	71	1700	2088
300	66	54	1680	2058
350	46	45	1770	1814
400	29	35·2	2150	1776
500	34·2	......	1170	......
600	23·9	......	1160	......
700	15·3	......	1330	......
800	8·9	......	1760	......
900	9·4	......	1310	......
1000	8·35	......	1980	......
1200	4·1	......	1690	......
1400	4·2	......	1210	......
1600	4·2	......	930	......
1800	1·9	......	1620	......
2000	2·4	......	1040	......
2300	0·9	......	2100	......
2600	0	......	......	......
3000	1·2	......	930	......
3500	1·2	......	680	......
4000	0	......	......	......

Comparison of Isopentane with other Substances at "Corresponding" Pressures.

The absolute temperatures (boiling-points) and molecular volumes of liquid and saturated vapour were read from the curves at pressures "corresponding" to those adopted in previous papers on this subject (Phil. Mag. Feb. 1892, p. 153; Trans. Chem. Soc. lxiii. p. 1191; Phil. Mag. Jan. 1894, p. 1); and are given in the table below:—

Ratio of Pressure to Critical Pressure.	Pressure.	Absolute Temperature.	Molecular Volume.	
			Liquid.	Saturated Vapour.
	millim.	°	cub. centim.	cub. centim.
·002949	73·8	247·25	......	......
·005898	147·5	260·8	......	......
·011795	295·1	276·2	112·94	......
·022411	560·7	292·4	115·86	31040
·044232	1107	312·3	119·84	16380
·088465	2213	336·0	125·24	8490
·14744	3689	356·3	130·68	5180
·20642	5165	371·35	135·50	3675
·29488	7378	388·65	140·29	2540
·44232	11040	410·2	152·93	1614
·58978	14755	426·95	165·15	1132
·73721	18445	440·8	180·35	813·5
·82568	20660	448·0	192·35	671·5
·88465	22130	451·6	204·05	580·0
·94363	23610	457·0	221·65	482·5
·97313	24350	459·1	237·7	425·5
1·00000	25020	460·8	306·5	306·5

The ratios of the absolute temperatures and of the volumes to the critical constants show that isopentane belongs to the same group as benzene and its halogen derivatives, ether, carbon tetrachloride, and stannic chloride. The actual values approach most closely to those of benzene, and for the sake of comparison both are given in the following table (p. 657).

The ratios of the actual to the theoretical densities of the saturated vapour for isopentane and benzene are also given. At the critical point the ratio is 3·73, agreeing very closely with those for the other substances in group I. (3·65 to 3·83) and also with the ratio for carbon dioxide (3·62) deduced from Amagat's observations.

From these results it may be concluded that the molecules of liquid isopentane are simple, like those of the gas.

Errata (p. 650).

Values of $\frac{10000}{bv}$ at

Volume	3·8	*for*	5·507	*read*	5·623
"	8·5	"	7·195	"	7·160
"	14	"	8·258	"	8·241

Ratio of Pressure to Critical Pressure.	Absolute Temperature / Abs. Critical Temperature.		Mol. Vol. of Liquid / Mol. Critical Volume.		Mol. Vol. Sat. Vapour / Mol. Critical Volume.		Actual Density Sat. Vap. / Theoretical Density.	
	Isopentane.	Benzene	Isopentane.	Benzene.	Isopentane.	Benzene.	Isopentane.	Benzene.
·002949	·5366	·5359	......	......	......	......	......	......
·005898	·5660	·5648	......	......	......	......	......	......
·011795	·5994	·5989	·3685	·3648	......	......	......	......
·022411	·6346	·6334	·3780	·3742	101·6	......	1·040	......
·044232	·6777	·6765	·3910	·3870	53·5	54·4	1·070	1·052
·088465	·7292	·7282	·4086	·4053	27·7	28·2	1·111	1·091
·14744	·7732	·7725	·4263	·4233	16 9	17·25	1·159	1·136
·20642	·8059	·8052	·4421	·4389	12·0	12·35	1·215	1·180
·29488	·8434	·8429	·4636	·4602	8·29	8·49	1·289	1·260
·44232	·8902	·8906	·4989	·4960	5·27	5·35	1·427	1·408
·58978	·9266	·9270	·5388	·5353	3·69	3·72	1·588	1·582
·73721	·9566	·9566	·5884	·5845	2·65	2·69	1·825	1·806
·82568	·9722	·9725	·6275	·6250	2·19	2·20	2·007	2·006
·88465	·9800	·9824	·6656	·6613	1·89	1 91	2·186	2·180
·94363	·9918	·9915	·7232	·7113	1·58	......	2·488	......
·97313	·9963	......	·7755	......	1·39	......	2·754	......
1·00000	1·0000	1·0000	1·0000	1·0000	1·00	1·00	3·73	3·71